THE ORGANIC CHEMISTRY OF SULFUR

Tetracovalent Sulfur Compounds

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PREFACE

This book is an attempt to present in a form convenient for reference the chemistry of organic compounds which in a broad sense are derivatives of sulfuric acid. It is an amplification of a portion of the material presented in lectures before classes in "Advanced Topics" at Northwestern University. The interest of organic chemists in this type of monograph and other demands upon the author's time will determine whether the remainder of sulfur chemistry will be covered in a second volume.

An effort has been made to include references to all the important literature covered by *Chemical Abstracts* to January 1, 1942. Information regarding important material which may have been omitted, as well as other comments and criticisms, will be welcomed. The boiling points and melting points of the compounds listed in the tables have not been critically evaluated. Many of these figures come from the early literature, and the great majority are uncorrected.

Acknowledgment is made of permission to reprint the tables on pages 4, 105, 227, and 584 from the *Journal of the American Chemical Society*. Acknowledgment also is made of permission from Professor A. J. Carlson to quote his summary of the physiological effects of saccharin.

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C. M. S.

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CHAPTER I

ESTERS OF SULFURIC ACID

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A. MONO ESTERS DERIVED FROM ALIPHATIC HYDROXY AND OLEFINIC COMPOUNDS

Although the formation of ethyl ether by the action of concentrated sulfuric acid upon ethyl alcohol was studied as early as 1540,[1] the intermediate[2] alkyl hydrogen sulfate was not noticed until much later.[3] Before the alkyl halides and alkyl sulfates became readily available the salts of alkyl hydrogen sulfates were frequently used as alkylating agents, and they are still so employed where reaction occurs readily in aqueous solution as in the preparation of thiols and sulfides. The importance of alkyl hydrogen sulfates as intermediates in the conversion of olefins into alcohols, ethers, and esters and the use of the alkali salts of a variety of the higher-molecular-weight esters as wetting agents and detergents have greatly augmented the interest in this class of compounds in recent years.

The important methods of preparation, general properties, and the reactions common to the hydrogen sulfates derived from a variety of aliphatic hydroxy compounds and olefins are treated first; these sections are followed by a more detailed discussion of important individual esters and their sundry derivatives.

METHODS OF PREPARATION

The mono esters of sulfuric acid have been for the most part obtained either by the action of a sulfating agent such as sulfur trioxide, chlorosulfonic acid, or sulfuric acid upon hydroxy compounds or by the addition of sulfuric acid to the olefinic linkage of unsaturated substances.

Sulfation of Alcohols with Sulfuric Acid. The early preparation of ethyl hydrogen sulfate has been mentioned.[3] The action of sulfuric acid upon the higher-molecular-weight alcohols was also studied many years ago. Dumas and Peligot[4] prepared cetyl hydrogen sulfate and also ceryl alcohol (1-hexacosanol),[5] *n*-octyl alcohol,[6] and the alcohols from wool fat[7] were later similarly converted into esters.

An excess of 100% sulfuric acid converts the normal primary alcohols into the alkyl hydrogen sulfates at room temperature without formation of the alkyl sulfates.[8] However, upon long standing a complex mixture of hydrocarbons separates from the acid. These are mostly of the paraffin series. Primary alcohols with branched chains, including isobutyl, isoamyl, and *act*-amyl, give in addition to esters, compounds which decolorize bromine water. The formation of these is greatest with isobutyl alcohol. Secondary and tertiary alcohols at first yield chiefly the esters, but these upon standing in the excess sulfuric acid are converted into hydrocarbons. The oily layer which slowly separates from the sulfuric acid contains a high percentage[9] of saturated hydrocarbons. The hydrogen necessary to produce these arises from a sort of disproportionation referred to as "conjunct polymerization"[10] that produces cycloölefins which remain in the acid solution. Cetyl alcohol gives a product melting at 50° that has the properties of paraffin wax. Cyclohexanol is converted into high-boiling hydrocarbons.[11] The triphenylcarbinyl hydrogen sulfate obtained from triphenylcarbinol[8] was found to be highly dissociated as indicated by its low molecular weight in sulfuric acid solution. Water decomposes it with regeneration of triphenylcarbinol.

In the commercial sulfation of high-molecular-weight aliphatic or naphthenic alcohols[12] with sulfuric acid it may be advantageous to add an inert solvent such as carbon tetrachloride or a saturated hydrocarbon. Two layers are formed, the excess sulfuric acid in one and the ester and inert material in the other. The addition of an alcohol such as *n*-butyl alcohol to a sulfation mixture in which cetyl or oleyl alcohol has been esterified aids in the separation of the alkyl hydrogen sulfate from excess sulfuric acid since upon the addition of water two layers are formed, practically all the sulfuric acid going into the water layer.[13] It has also been claimed [14] that adding glycerol or its sulfuric acid ester assists in the removal of excess sulfuric acid. Another procedure for separating the ester from excess acid involves neutralization of the reaction mixture with calcium hydroxide or oxide [15] and removal of insoluble calcium sulfate. If the sulfuric acid is not to be removed, neutralization of the crude sulfation mixture with solid sodium carbonate or hydroxide is claimed [16] to be advantageous. Alternatively 50% sodium hydroxide solution has been used.[17] Solid sodium chloride may also be employed to convert an alkyl hydrogen sulfate to the sodium salt.[17a]

$$ROSO_3H + NaCl \xrightarrow{\Delta} ROSO_3Na + HCl$$

Separation of any alcohol not converted to the ester as well as separation of impurities may be effected by neutralizing the reaction mixture with aqueous alkali, adding an alcohol miscible with water such as methanol, and extracting the solution with petroleum ether.[18] Unsulfated material may otherwise remain dispersed in the aqueous solution even though ordinarily insoluble in water.

Sulfuric acid may be completely converted into an alkyl hydrogen sulfate by adding it to an excess of an anhydrous alcohol [19] and removing the water formed in the reaction by distilling it off with some of the unchanged alcohol below 85°. Solutions of the esters from methyl to *n*-amyl in the corresponding alcohols were found to give precipitates of arylammonium salts when an aromatic amine was added. So far as is known no appreciable amount of the neutral ester

$$ROSO_3H + C_6H_5NH_2 \rightarrow ROSO_3H_3NC_6H_5$$

is produced even in anhydrous solution with excess alcohol. If it were, ether resulting from the action of alcohol with the ester would become noticeable. Sulfation in the presence of a dehydrating agent such as acetic anhydride is also useful in causing the reaction to go to completion.[19a] A study of the extent of ester formation at equilibrium for a number of primary alcohols and varying concentrations of sulfuric acid [20] gave the results shown in Table I. By the use of fuming sulfuric acid reaction mixtures containing low concentrations of water were obtained because most of the ester is formed by the irreversible reaction between the alcohol and sulfur trioxide. With alcohols above *n*-butyl, however, the sulfur trioxide if present in appreciable quantities induces side reactions which invalidate the results of quantitative

$$RCH_2OH + SO_3 \rightarrow RCH_2OSO_3H$$

determinations. The values of K given in the table are for equimolecular quantities of the reactants at a temperature of 25°. The high values of K for methanol and isobutyl alcohol are to be noted. Equilibrium in these reactions was practically attained in a few hours at 25°. At 75° or higher only a few minutes is required.

TABLE I

Alcohol	96.7% H_2SO_4		5.20% SO_3		22.6% SO_3		31.98% SO_3	
	K	$RHSO_4$, %	K	$RHSO_4$, %	K	$RHSO_4$, %	K	$RHSO_4$, %
Methyl	3.30	61.2	3.42	66.0	3.62	70.5	3.67	73.2
Ethyl	1.76	52.6	2.02	59.8	2.08	65.1	1.98	67.7
β-Chloroethyl	2.00	55.0	2.00	59.8	2.44	66.7	2.55	70.0
n-Propyl	2.30	56.8	2.38	61.9	2.59	67.3	2.76	70.6
n-Butyl	2.69	58.8	2.83	63.9	2.82	68.1	3.04	71.5
Isobutyl	3.14	60.8	3.32	65.7	....	....	....	....
n-Amyl	2.78	59.2	2.98	64.4	....	....	....	....
n-Hexyl	2.57	58.3	2.70	63.3	....	....	....	....

It was observed by Cochenhausen[7] that cholesterol could not be esterified by sulfuric acid, the insoluble cholesterone being formed. More recently it has been claimed[21] that if an alcohol of this type is esterified by boric acid before adding to 90% or over sulfuric acid the hydrogen sulfate may be obtained. A temperature of 30° is most suitable for converting oleyl alcohol into the ester by means of sulfuric acid.[22] At a lower temperature the relative amount of addition to the double bond is increased.

The question arises as to the mechanism by which an alcohol reacts with sulfuric acid. As in the esterification of carboxylic acids the oxygen utilized in forming the water might come from either the sulfuric acid or the alcohol. Since neopentyl alcohol is converted into the hydrogen sulfate without rearrangement[23] it is evident that here the alcohol oxygen is not disturbed since any reaction replacing the hydroxyl group yields rearranged products.

$$(CH_3)_3CCH_2OH + HOSO_3H \rightarrow (CH_3)_3CCH_2OSO_3H + H_2O$$

It is likely that this mechanism also holds for trifluoroethanol[24] where reaction occurs with difficulty. The course of the reaction in other primary alcohols and secondary alcohols is not known but could readily be determined by the use of oxygen with an abnormal isotopic distribution by the reactions indicated.

$$RMgBr \xrightarrow{\overset{*}{O}_2} R\overset{*}{O}MgBr \xrightarrow{H_2O} R\overset{*}{O}H \xrightarrow{H_2SO_4} R\overset{*}{O}SO_3H + H_2O$$

Undoubtedly tertiary alcohols react with sulfuric as with other strong acids with elimination of the alcoholic hydroxyl.

It has been found by Aschan and Schwalbe[25] that the addition product of ether and sulfuric acid, referred to as "diethyl oxonium sulfate," is a particularly useful sulfating agent for terpene alcohols such as menthol, isoborneol, and borneol. Only one hydroxyl of polyhydric alcohols reacts. The reagent acts less readily with olefin bonds than with alcohol groups. The use of this reagent has therefore made possible the preparation of ricinoleic acid hydrogen sulfate in 60% yields.[26]

$$(C_2H_5)_2OH_2SO_4 + CH_3(CH_2)_6CHOHCH{=}CH(CH_2)_7COOH \rightarrow$$
$$H_2O + (C_2H_5)_2O + CH_3(CH_2)_6CH(OSO_3H)CH{=}CH(CH_2)_7COOH$$

Phenyl ether and benzyl ether do not form the oxonium salts[25] with sulfuric acid. A mixture of sulfur dioxide and petroleum ether is a satisfactory sulfating solvent for certain reactions.[27a]

The sulfate of benzyldimethylamine and similar amines[27b] reacts with an alcohol when the mixture is heated at 80–150°. It may be expected that the weaker the base from which a salt is derived the more readily will the salt react with an alcohol.

$$ROH + R'N(CH_3)_2H_2SO_4 \rightarrow ROSO_3HN(CH_3)_2R'$$

Sulfation with Sulfur Trioxide. The sulfation of an alcohol with sulfur trioxide, fuming sulfuric acid (oleum), a pyrosulfate, or an addition compound of sulfur trioxide differs from esterification with sulfuric acid in that the reaction does not reach an equilibrium value and is not reversible. Hence only equimolecular quantities of the two reactants need ordinarily be used. As sulfur trioxide alone gives side reactions of oxidation or charring with all but a few alcohols it is rarely used directly as a sulfating agent unless diluted with an inert solvent. A variety of procedures have been described in the patent literature[28a] for the "sulfonation" of castor oil or ricinoleic acid by the action of oleum or sulfur trioxide in solvents which include sulfur dioxide, carbon tetrachloride, trichloroethylene, acetic acid, acetic anhydride, and acetyl chloride. The products contain sulfonic acids as well as hydrogen sulfates in most if not all instances. The reaction of the sulfur trioxide of oleum with an alcohol occurs practically instantaneously even at 0°. The use of oleum has the disadvantage of necessitating the removal or separation of the sulfuric acid from the ester after the sulfation is complete. This reagent is therefore frequently less convenient than an addition product of sulfur trioxide such as pyridine sulfotrioxide[28b] or dioxane sulfotrioxide.[29] β-Chloroethyl ether and similar ethers[30] dissolve sulfur trioxide readily at ordinary temperatures without appreciable reaction, and such a solution is a convenient sulfating agent. It is probable that here also a coordination compound is formed as with dioxane or pyridine. These addition complexes show different orders of activity which vary inversely as

$$(ClCH_2CH_2)_2OSO_3 > O(CH_2CH_2)_2OSO_3 > C_6H_5NSO_3$$

the stability of the coordination compound. The pyridine complex is the least reactive, and the chloroethyl ether probably shows the greatest activity. The pyridine compound reacts with unsaturated alcohols without materially affecting the double bonds[28] whereas the dioxane sulfotrioxide reacts with the alcohol group more rapidly than with the unsaturated linkage but the double bond is sulfated in the presence of excess reagent.

Another reagent which transfers the equivalent of sulfur trioxide to an alcohol but leaves an inorganic salt as the residue is a pyrosulfate.[31] This is more reactive than pyridine sulfotrioxide,[32] and since the pyrosulfates have generally been used in pyridine solution undoubtedly the pyridine compound is formed first. Although the action of potassium pyrosulfate with phenolic compounds has been well studied, corresponding information for the direct action upon alcohols seems to be lacking. The addition product of sulfur trioxide and sodium nitrite has been patented.[32b]

$$ROH + K_2S_2O_7 \rightarrow ROSO_3K + KHSO_4$$

Sulfation with Chlorosulfonic Acid. One of the most useful methods of sulfating an alcohol, particularly on an industrial scale,[33] is to treat it with chlorosulfonic acid, a reagent introduced many years ago by Claësson[34] in his preparation of methyl and ethyl hydrogen sulfates. Since hydrogen chloride is only slightly soluble in a sulfation mixture the reaction goes to completion rapidly even at a low temperature. To decrease the by-products a solvent such as ethyl ether,[35]

$$ROH + ClSO_3H \rightarrow ROSO_3H + HCl \uparrow$$

β-chloroethyl ether,[30] ethyl acetate,[36a] or carbon tetrachloride[36b] may be used. Mixing the alcohol such as oleyl or cetyl with some previously prepared alkyl hydrogen sulfate has also been suggested.[37] If oleyl or other unsaturated alcohol is treated with the chlorosulfonic acid and the hydrogen chloride is kept in contact with the sulfation mixture halogenated alkyl hydrogen sulfates result.[38] On the other hand when the hydrogen chloride escapes, the unsaturated ester can be obtained as in the formation of undecenyl hydrogen sulfate from the alcohol and chlorosulfonic acid in ether.[39]

The addition products of pyridine[40a] and dioxane[29] with chlorosulfonic acid are useful sulfating agents as, for example, in the esterification of castor oil. It is not entirely clear as yet whether these reagents are the same as those obtained from sulfur trioxide. It seems probable, however, that they are different, the chlorosulfonic acid forming a chlorosulfonate rather than losing hydrogen chloride and giving the sulfotrioxide type of reagent. The chlorosulfonic acid addition compound has been found to require a higher temperature than the coordination complex derived from sulfur trioxide before it exerts a sulfonating action. The addition product of chlorosulfonic acid and urea or other amide has also been patented[40b] as a sulfating agent.

$$O(C_2H_4)_2OHO_3SCl + ROH \rightarrow O(C_2H_4)_2OHO_3SOR + HCl$$

A recently developed reagent of considerable interest is sodium chlorosulfonate. This reacts with alcohols to give a sodium alkyl sulfate directly[41] and in the case of unsaturated alcohols esterifies the hydroxyl without disturbing the olefin linkage.

$$ROH + ClSO_3Na \rightarrow ROSO_3Na + HCl$$

Miscellaneous Sulfating Agents. Heating dry sodium bisulfate with an anhydrous alcohol yields the ester, but this is apparently because of formation of sulfuric acid from decomposition of the bisulfate.[42]

$$3NaHSO_4 \rightarrow Na_3H(SO_4)_2 + H_2SO_4$$

$$H_2SO_4 + C_2H_5OH \rightarrow C_2H_5HSO_4 + H_2O$$

It has been known for many years[43] that heating aminosulfonic (sulfamic) acid with ethanol gives ammonium ethyl sulfate. More recently this reagent has been applied to higher members of the series,[44] and since it is now[45] readily available commercially interest in its use will undoubtedly increase. Arylaminosulfonic acids have also been suggested[46] as sulfating agents, reaction with the higher alcohols

$$C_2H_5OH + NH_2SO_3H \rightarrow C_2H_5OSO_3NH_4$$

occurring at temperatures above 100°. A reagent closely related to

$$C_{18}H_{37}OH + CH_3C_6H_4NHSO_3H \xrightarrow{110^\circ} C_{18}H_{37}OSO_3NH_3C_6H_4CH_3$$

these is aminodisulfonic acid,[47] $NH(SO_3H)_2$, whose ammonium salt has a sulfating action.

$$n\text{-}C_4H_9OH + NH(SO_3NH_4)_2 \rightarrow n\text{-}C_4H_9OSO_3NH_4 + NH_2SO_3NH_4$$

Sulfuryl chloride reacts with excess methanol to give methyl hydrogen sulfate as one of several products.[48] A mixture of sulfur dioxide and chlorine gives about the same results.[49] The preparation of sodium lauryl sulfate and similar compounds by hydrolysis of lauryl chlorosulfonate has been described.[50]

$$CH_3OH + SO_2Cl_2 \rightarrow CH_3OSO_2Cl + HCl$$
$$CH_3OSO_2Cl + CH_3OH \rightarrow CH_3HSO_4 + CH_3Cl$$

$$C_{12}H_{25}OH \xrightarrow{SO_2Cl_2} C_{12}H_{25}OSO_2Cl \xrightarrow{NaOH} C_{12}H_{25}OSO_3Na$$

Oddly enough sulfur monochloride reacts with ethanol to give ethyl hydrogen sulfate.[51] Possibly the reaction proceeds according to this equation.

$$3S_2Cl_2 + 4C_2H_5OH \rightarrow C_2H_5HSO_4 + 3C_2H_5Cl + 3HCl + 5S$$

When an alcohol is heated under pressure with sulfur dioxide and pyridine in the range of 90° to 175° in the presence of copper, a copper salt, or iodine, sulfation occurs.[52] It was suggested that a disproportionation might precede ester formation.

$$3SO_2 \rightarrow 2SO_3 + S$$

Heating a higher-molecular-weight alcohol with potassium ethyl sulfate to 150° results in a transfer of the sulfate group [53] and the evolution of ethanol.

$$C_{16}H_{33}OH + C_2H_5OSO_3K \rightarrow C_{16}H_{33}OSO_3K + C_2H_5OH$$

Reaction of Olefins with Sulfuric Acid; General. Because of the manner in which sulfuric acid adds to the olefin bond all alkyl hydrogen sulfates obtained by this reaction except for the ethyl ester contain a secondary or tertiary alkyl group. Since n-alkyl bromides may be obtained by the addition of hydrogen bromide to α-olefins under certain conditions, particularly in the presence of a peroxide catalyst,[54] it seemed possible that n-alkyl hydrogen sulfates might be prepared similarly, but it has been found [55] that 1-pentene reacts with 85% sulfuric acid in the presence of peroxides to give only the secondary ester.

A comprehensive study of the absorption of gaseous olefins by various concentrations of sulfuric acid has been made by Davis and coworkers.[56a] It was found that the rate of absorption is proportional to the pressure of the olefin when the reaction is carried out at constant volume, and stirring the sulfuric acid has no effect upon the rate except as it increases the area of the acid surface. The reactions apparently occur in a thin surface film rather than in the main body of the liquid. The rate of absorption depends greatly upon the olefin. Thus for 80% and higher sulfuric acid propene dissolves about 300 times as rapidly as ethylene. Propene and 1-butene dissolve at about the same rate, whereas 2-butene dissolves from 1.7 to 2.6 times as fast as these. Trimethylethylene is absorbed several times as rapidly as isobutylene, which in turn reacts from 10 to 80 times as fast as 2-butene. Isopropylethylene reacts at about the same rate as propene. It was noted that isobutylene was converted directly into *t*-butyl alcohol when absorbed by 60% sulfuric acid, but propene gave only the isopropyl hydrogen sulfate. 2-Butene is largely converted to the alcohol in 80% acid.[56b] The application of these results and those of previous workers to the analysis of mixtures of olefins has been discussed in detail.[56]

This marked variation in the reactivity of olefins toward sulfuric acid has been utilized commercially in effecting the preferential absorption of the unsaturated components present in the gas obtained from the cracking of petroleum.[57]

The absorption of gaseous olefins by sulfuric acid is facilitated by the presence of various catalysts, usually metallic salts. Thus it is reported that the salts of metals in the eighth group of the periodic table such as nickel cyanide increase the reaction rate [58] for olefins containing more than three carbon atoms. In other patents [59] complex metallic cyanides have been specified. Other catalysts are listed under the description of the preparation of individual esters. The reaction of normally gaseous olefins may be effected to advantage by first liquefying them under pressure and then treating with sulfuric acid.[60]

To obtain the best yields of acid sulfates it is necessary to use the most dilute sulfuric acid that will combine with a given olefin, as polymerization increases rapidly with increase in concentration of the acid, particularly for the higher olefins. Propylene and also the butylenes [61] polymerize with high concentrations of sulfuric acid. Propylene with 90–92% acid forms 4-methyl-1-pentene,[62] but with 98% acid [63] higher-boiling products result. With excess concentrated acid, isobutylene and higher olefins are converted into a complex mixture of hydrocarbons in which paraffinic and cycloölefinic compounds predominate.[64] In the presence of copper and mercurous sulfates, even ethylene is converted by 95% acid into a mixture of hydrocarbons of various types.[65]

The earlier work [66] on the reactions of the pentenes was with commercial amylene and hence led to little of scientific value. Systematic studies [67,68] of the behavior of pure pentenes with sulfuric acid have shown that pentenes with two alkyl groups attached to an unsaturated carbon react more rapidly than their isomers. Trimethylethylene and *unsym*-methylethylethylene dissolve some twenty times as fast in 60% sulfuric acid as do 1-pentene and 2-pentene. It was not possible to obtain the alkyl hydrogen sulfate from isopropylethylene,[67] polymerization only taking place. The butenes and pentenes may be grouped according to their behavior with sulfuric acid [69] as follows. (1) Isobutylene, trimethylethylene, and *unsym*-ethylmethylethylene dissolve readily in 60–70% acid to give tertiary alcohols directly. (2) 1-Butene, 2-butene, 1-pentene, and 2-pentene dissolve in 75–80% acid to yield the alkyl hydrogen sulfates. For 2-pentene the addition product is chiefly methyl-*n*-propylcarbinyl hydrogen sulfate, although some of the other ester is also present.[70] (3) Isopropylethylene forms only polymers. The behavior of the hexenes and heptenes is comparable to that of the pentenes except for their slightly greater tendency to polymerize.[68, 71] The product from 2-hexene gives 77% of 2-hexanol.[72a] 3-Hexene behaves similarly.[72b]

The possibility of obtaining alkyl hydrogen sulfates even under favorable conditions decreases with increasing molecular weight above the pentenes and hexenes.[68, 71b, 73] With hexadecene and above, it has been reported [71b] that it is not possible to obtain the ester under any conditions. Despite these statements there are many examples in the patent literature of the formation of high-molecular-weight alkyl hydrogen sulfates from olefins, and polymerization seems to depend more upon the structure of the olefin than upon its molecular weight.

A proper variation in the reaction conditions such as the use of a solution of the olefin in some inert material reduces polymer formation. Lyons [74] has described the sulfation of olefins in liquid sulfur dioxide with 75 to 93% sulfuric acid under pressure at 0° to 10°. Bertsch [75] has obtained wetting agents and detergents by the action of concentrated sulfuric acid upon olefins such as 1-hexadecene (cetene) in the presence of butyl alcohol or other diluents such as benzene or trichloroethylene at −5°. A low-boiling saturated hydrocarbon may be added to the sulfation mixture in order to control the temperature.[76]

A hydrocarbon mixture containing saturated and unsaturated compounds gives both mono and dialkyl sulfates with 85 to 100% sulfuric acid.[77] It is also claimed that polymers from low-molecular-weight olefins can be sulfated.[78] If a cracked petroleum product is treated with 65–87% sulfuric acid and the solution "aged" at 25–60° it will then dissolve more of the petroleum product.[79]

The action of sulfuric acid upon unsaturated compounds containing hydroxyl groups is of considerable interest. Concentrated sulfuric acid with allyl alcohol causes tar formation,[80] but by adding the alcohol to 50% sulfuric acid a small yield of allyl hydrogen sulfate results.[81] From 100 g. of alcohol 40 g. of barium salt was isolated. The action of even dilute sulfuric acid upon geraniol causes ring formation and hydration, 5% acid giving chiefly terpin hydrate.[82a]

Oleyl alcohol reacts with sulfuric acid both at the olefinic linkage and at the alcohol group.[83] The rate of reaction with the double bond was reported to be nearly uniform over the temperature range 0–40°, whereas the activity of the hydroxyl group increases markedly with rise in temperature. The sulfation of oleyl esters has been described.[84a] Sulfated methylheptadecenylcarbinol has been mentioned also.[84b]

The action of sulfuric acid upon oleic acid results in the formation of both possible hydrogen sulfates [85] as well as sulfonic acids [83a] of unknown structure. The maximum yield of 10-hydroxystearic acid [85f] reported from hydrolysis of the esters is 31%. Isoöleic and elaidic acids give similar results.[87c] Treatment of olein with strong sulfuric acid [86, 85c] yields hydrogen sulfates that give 10-hydroxystearic acid, probably mixed with the 9-isomer. Methods devised for the analysis of sulfonated oils [87a] indicate that the formation of sulfonic acids also occurs to an appreciable extent. The technical literature [87b] dealing with the "sulfonation" of many oils is extensive, but precise information as to the identity of the reaction products is not available.

The sulfation of oleic amide with sulfuric acid has been mentioned,[87c] but a pure hydrogen sulfate was not isolated.

The products obtained by the action of sulfuric acid of varying concentrations upon ricinoleic acid [88, 26] and its esters,[89a] particularly castor oil,[89b] have considerable industrial importance in the textile industry under the name "Turkey red oil" as wetting agents. The usual methods of preparation of "sulfonated castor oil" using concentrated sulfuric acid or oleum lead to the formation of a complex mixture [90a] of compounds consisting of hydrogen sulfates of ricinoleic acid in which either the hydroxyl group is esterified or sulfuric acid has added to the double bond but not both in the same molecule. In spite of the large amount of work expended upon studies of these compounds as indicated by the voluminous patent literature,[89c] individual substances have rarely been isolated and the structure of the sulfonic acids obtained by the action of sulfuric acid at 100° is entirely unknown.

Useful products have also been obtained by the sulfonation of the methyl ether of ricinoleic acid[90b] and from an ester resulting from the action of hydrogen cyanide upon ricinoleic acid followed by hydrolysis and esterification.[90c]

Unsaturated amines including allylamine[91] and the higher members of the series[92] have been converted into esters by the action of sulfuric acid.

Conjugated dienes are polymerized by acid, but 1,5-hexadiene[93] gives with sulfuric acid a mixture of the cyclic ester and the bis-(hydrogen sulfate), both yielding the same glycol on hydrolysis.

In only a few instances have the alkyl hydrogen sulfates or their salts obtained from olefins been isolated; in most investigations the esters have either been hydrolyzed to the corresponding alcohols by diluting the reaction mixture and distilling[94] or neutralized and used as commercial products having wetting or detergent properties.

SALTS OF ALKYL HYDROGEN SULFATES AS DETERGENTS AND WETTING AGENTS

It was remarked by Möslinger[95] that barium *n*-octyl sulfate was somewhat soluble in water and that the potassium salt was a soaplike water-soluble material which was stable in air. This is probably the first intimation that compounds of this type might find use as washing agents in water containing alkali-earth salts. No commercial development in this direction was possible until the higher-molecular-weight alcohols became available in large amounts at a reasonable price. Almost as soon as a catalytic method of reducing the esters of fatty acids was devised, interest in the salts of the *n*-alkyl hydrogen sulfates containing about ten to eighteen carbon atoms was evidenced by the appearance of numerous patents on the preparation and uses[96] of these compounds. The various methods of preparation have already been outlined. A number of reviews are available in technical journals[97] discussing the utilization of these new commercial products. Since their detergent action is unaffected by moderately hard water or acid solutions and since they have good wetting properties they are now in considerable demand for both industrial and domestic use.

During recent years many patents have been granted which deal with esters other than those derived from the straight-chain alcohols.

Sulfates of branched-chain secondary alcohols have been found to be good wetting agents[98] although less effective in detergent action than those having the polar group on the end of the chain.

The hydrogen sulfates of alcohols containing one or more halogen atoms have been suggested as wetting agents and detergents.[99] A variety of hydroxy compounds containing one or more other functional groups have been converted into sulfuric acid esters, and the esters have been the subject of patent claims. Among these alcohols are substances with the formulas

$C_{17}H_{33}CON(CH_3)CH_2CH_2OCH_2CH_2OH$

$C_{17}H_{33}COOCH_2CH_2OCH_2CH_2OH$ [100]

$C_{17}H_{33}COOCH_2CH_2N(CH_2CH_2OH)CH_2CH_2CHOHCH_3$

$C_{17}H_{35}CONHCH_2(CHOH)_4CH_2OH$

$RCONHCH_2CH_2OH$

$RCONR'CH_2CH_2OH$

$C_6H_5SO_2N(C_4H_9)CH_2CH_2OH$ [101]

which are of the amide or ester type. Poly ethers having also an amine group in the molecule such as $ArN(R)CH_2CH_2(OC_2H_4)_nOH$, where n is 2 or 3, have been sulfated,[102] as have a series of sulfide alcohols,[103] $RSCH_2CH_2OH$. A variety of cyclic alcohols ranging from cyclohexanol and the terpene alcohols[104] through those resulting from the reduction of hydroxybiphenyls[105] to the ethylanilide of cholic acid[106] and the alcohols produced by reduction of resin acids[107] have been claimed to yield hydrogen sulfates which are of industrial value in one way or another. Many other miscellaneous hydroxy compounds have also been sulfated.[108] Practically all the literature in this field has been confined to patents and patent reviews. Detailed scientific studies of the properties of pure chemical substances are therefore lacking, and neither a satisfactory correlation of the structures of mono esters of sulfuric acid and their effects upon the surface tension of water nor the correlation of surface-tension effects with wetting and detergent properties is possible at present. The information that is available deals with the straight-chain normal alcohol derivatives. The solubility in water of the calcium and magnesium salts of cetyl hydrogen sulfate[109] is very slight, and hence the alkali salts of this are less useful as detergents than the lower members of the series.

Aside from the solubility the hydrogen sulfate salts obtained from lauryl, cetyl, and oleyl alcohols all have about the same detergent power.[110] However, in the scouring of wool, sodium oleyl sulfate has been found to be superior to the lauryl compound.[111] The ammonium and sodium salts of the cetyl compound were found[109] to exert an effect upon the surface tension of water similar to that of sodium ricinoleate. The interfacial tension of aqueous solutions of a number of salts of dodecyl (lauryl), tetradecyl, hexadecyl (cetyl), and octadecyl hydrogen sulfates against paraffin oil at various temperatures has been reported.[112] It has been reported that the presence of a sodium alkyl sulfate in a solution produces considerable error in the colorimetric measurement of the *p*H.[113]

ANALYSIS OF ALKYL HYDROGEN SULFATES

Because of the many commercial products which now contain salts of alkyl hydrogen sulfates it is of decided interest to have analytical methods available for distinguishing between these and soaps, and also for estimating quantitatively the sulfates in various mixtures.

Estimation by precipitation of the barium alkyl sulfate is not satisfactory,[114] and oxidation with potassium permanganate is likewise not quantitative. A procedure involving precipitation as the benzidine salts and extraction from benzidine sulfate with hot alcohol followed by titration with standard alkali may be employed, but other soaplike materials such as sulfonates interfere.[114] Another procedure useful in some circumstances consists in the hydrolysis of the esters by heating with strong hydrochloric acid and weighing the alcohol produced.[115a, b] Sodium lauryl sulfate undergoes a slow decomposition at 110° with formation of sodium acid sulfate and the loss in weight is a rough

$$C_{12}H_{25}NaSO_4 \xrightarrow{110^\circ} C_{12}H_{24} + NaHSO_4$$

measure of the ester present.[115c] Commercial sulfated alcohols contain ether-extractable material which is apparently a mixture of unreacted alcohol, fatty acids, and unhydrolyzed fat, and this complicates analysis.[115c] In addition, sodium sulfate is always present in considerable amount. The alcohol extract of a commercial product apparently contains all the sodium alkyl sulfate, but it is difficult to free this from the alcohol without charring the residue. Hydrolysis of a product containing a sodium alkyl sulfate with hydrochloric acid of known concentration followed by titration with alkali permits an estimate of the amount of ester.[115c] The rate of hydrolysis can be followed approximately by the amount of alcohol which separates from solution. For a more extensive comparison of analytical methods the article of Biffen and Snell[115c] should be consulted.

REACTIONS OF ALKYL HYDROGEN SULFATES

From a practical standpoint the most important reaction of alkyl hydrogen sulfates is their hydrolysis to the corresponding alcohols. Ethyl, isopropyl, and *sec*-butyl alcohols made by this reaction are now on the market at a low cost, and undoubtedly others will be produced whenever there is a sufficient demand. It is claimed that secondary alcohols of three to six carbons may be obtained[116] by partial distillation of the aqueous hydrogen sulfate solution, the alcohols collecting in the distillate. Various types of apparatus and procedures have been devised for carrying out the hydrolysis efficiently.[117] The hydrolysis of individual alkyl hydrogen sulfates is elaborated upon in later sections.

In the instances in which reactions of alkyl hydrogen sulfates or their salts have been studied for several members of the series it is noticeable that the methyl ester is more reactive than its higher homologs. Thus in the formation of ethers from alkyl hydrogen sulfates and alcohols, methyl ether[118] is evolved readily at 110°, while for the ethyl[2, 119] and higher homologs[120] a temperature of 130–140° is apparently necessary for the reaction to proceed at a moderate rate. Similarly in the reaction of alkyl potassium sulfates with sodium sulfinates[121] the methyl compound reacts slowly in a boiling aqueous solution while with the higher homologs no sulfone formation is detectable unless the reaction mixtures are heated to a higher temperature under pressure.

Fusion of a mixture of a sodium or potassium alkyl sulfate with a metal nitrite[122] gives small yields of the nitro compound and alkyl nitrite. Typical results are listed in Table II. Potassium nitrite gives about the same yields as the sodium compound, while with calcium

TABLE II

POTASSIUM ALKYL SULFATES AND SODIUM NITRITE

R =	$KRSO_4$, grams	$NaNO_2$, grams	RNO_2, grams	RONO, grams
Methyl	30	20	2.4	0.5
Ethyl	32.8	14	2.3	1.3
n-Propyl	35	14	2.0	0.5
Isobutyl	20	8	2.6	0.4
Isoamyl	20	9	2.5	0.9

and barium nitrites somewhat lower results were obtained. During the fusions a considerable amount of the alcohol is produced. The source of the water necessary for the hydrolysis of the alkyl potassium sulfate is unknown as the compounds were presumably dry at the start. Since nitric oxide was evolved continuously during the reaction it is possible that the alkyl nitrites come from the reaction of nitrous acid with the alcohols rather than from the initial reactants. The fusion mixture containing potassium methyl sulfate liberated some methylamine as a by-product. The nitroethane was found to contain a small amount of a nitrobutane. The formation of either nitrobutane or of methylamine is not easy to explain. The temperature at which reaction begins ranges with the various alkyl compounds from 90° to 140°; this is lowered slightly by the addition of a small amount of water to the reaction mixture. Mixing the reactants with sodium carbonate is claimed[123] to produce higher yields of the nitro compounds.

Dry distillation of a mixture of an alkyl potassium sulfate and potassium cyanide results in varying yields of a mixture of the alkyl cyanides and isocyanides.[124] For the cyanides other than ethyl the

$$RKSO_4 + KCN \rightarrow RCN + K_2SO_4$$

yields, although not given accurately, were reported to range from 15 to 40%. Adding a small amount of water to the reaction mixture gives a slightly smaller yield of cyanide with an increase in the isocyanide up to the time the reaction mixture becomes dry. Further heating yields more of the cyanide uncontaminated with isocyanide. A further study of this reaction making use of a higher-boiling solvent might yield results of considerable interest.

TABLE III

R ⟶	METHYL	ETHYL	*n*-PROPYL	ISOBUTYL	ISOAMYL
% RNC =	2.4	4.3	2.2	1.4	?
% RCN =	...	40.	...	...	...

The reaction between potassium sulfide or potassium hydrogen sulfide and an alkyl sodium sulfate occurs readily in aqueous solution. For the methyl compound[125] the reaction becomes appreciable at 30°

$$CH_3NaSO_4 + KSH \rightarrow CH_3SH + KNaSO_4$$

when a concentrated solution of potassium hydrogen sulfide is used. The alkyl sulfide occurs as a by-product in the reaction, probably owing to the following equilibrium which would induce sulfide formation.

$$CH_3SH + KSH \rightleftharpoons CH_3SK + H_2S$$

$$CH_3SK + CH_3NaSO_4 \rightarrow (CH_3)_2S + KNaSO_4$$

In the preparation of ethanethiol[126] the use of calcium ethyl sulfate reduces the formation of sulfide to a minimum, probably because calcium hydroxide is a somewhat weaker base than sodium hydroxide, which would reduce the amount of ethanethiol present as a salt in the solution. *n*-Butyl sulfide has been obtained in good yields[127] by refluxing a solution containing sodium sulfide and sodium *n*-butyl sulfate for several hours. If the solution is distilled slowly a considerable amount of 1-butanethiol is produced indicating the stepwise nature of the reaction. Isoamyl sulfide has been prepared[128] from calcium isoamyl sulfate and an alkali sulfide.

Esters of carboxylic acids are obtainable by heating the free acids with alkyl hydrogen sulfates provided that there is some reagent to remove free sulfuric acid.[129] Ammonium sulfate or a secondary or tertiary phosphate is suitable for this.

The pyrolysis behavior of alkyl hydrogen sulfates and their salts may be generalized by the statement that all the compounds except the methyl ester yield chiefly olefins and the behavior of the methyl compound depends upon the particular salt employed. By heating to 130–140° methyl hydrogen sulfate is converted into methyl sulfate and sulfuric acid.[130] The reaction is reversible, the reaction mixture at 150–160° containing approximately three moles of methyl hydrogen sulfate to one of sulfuric acid and of methyl sulfate.[131] This reaction is reversed at ordinary temperatures by dissolving methyl sulfate in 100% sulfuric acid.[132]

$$(CH_3)_2SO_4 + H_2SO_4 \rightarrow 2CH_3HSO_4$$

Methyl ammonium sulfate rearranges[133] upon heating to methylammonium hydrogen sulfate. The reaction begins at 100° and proceeds rapidly at 220° and above. As indicated by the change in acidity of the mixture it was found to be practically complete in 15 minutes at 275°. Above 220° a side reaction occurs to a slight extent, ethylene being evolved.

$$CH_3NH_4SO_4 \rightarrow CH_3NH_3OSO_3H$$

$$2CH_3NH_4SO_4 \rightarrow C_2H_4 + 2NH_4HSO_4$$

An 85.6% yield of methylamine was first reported as obtainable under the best conditions, but later workers[134] found the products of the reaction to be a mixture of the salts of the three methylamines, the maximum yield of methylamine obtainable being only 27% of the theoretical amount. Methyl phenylammonium sulfate was found[41] to rearrange more readily than the simple ammonium salt.

$$CH_3(C_6H_5NH_3)SO_4 \rightarrow (C_6H_5NH_2CH_3)HSO_4$$

Heating the pyridine salt of a higher-molecular-weight alkyl hydrogen sulfate above 130° gives an emulsifying agent[135] which may be $(RNC_5H_5)HSO_4$. Potassium methyl sulfate decomposes at 220° to 280° with formation of methyl ether.[136] This reaction is accelerated by the presence of methyl sulfate. Sodium methyl sulfate gives a 7%

$$2CH_3KSO_4 \rightarrow (CH_3)_2O + K_2S_2O_7$$

yield of methyl sulfate in addition to the methyl ether reaction.

$$2CH_3NaSO_4 \rightarrow (CH_3)_2SO_4 + Na_2SO_4$$

Calcium, barium, strontium, and lithium methyl sulfates give only a trace of methyl ether, methyl sulfate being the main product. These salts decompose below 200° and for the strontium salt decomposition was evident even at room temperature.

The decomposition of ethyl hydrogen sulfate in a vacuum[137] gives a small yield of ethyl sulfate, but at ordinary pressures the reaction is the common one leading to the formation of ethylene.[138] The reverse reaction will be mentioned later (see p. 25). Distillation of a mixture containing barium ethyl sulfate gives ethyl sulfate as one of the chief products.[139] The potassium salts of ethyl, isobutyl, and isoamyl hydrogen sulfates give both the olefin and the corresponding alcohol[140] when heated above 250°. In addition, the ethyl compound yields a small amount of ethyl ether. Ethyl, *n*-propyl, and isobutyl ammonium sulfates do not rearrange[133,141] to amine salts, the olefins being evolved instead. *n*-Octyl barium sulfate[6] gives octylene at 100°. Heating an alkyl hydrogen sulfate to about 300° with a salt capable of reacting with the resulting sulfuric acid to give an inert compound facilitates formation of the olefin.[142]

INDIVIDUAL ALKYL HYDROGEN SULFATES AND THEIR DERIVATIVES

Methyl Hydrogen Sulfate. Equimolecular quantities of methanol and surfuric acid at a temperature of 100° or below give only methyl hydrogen sulfate,[143] whereas the use of an excess of alcohol and distillation of the reaction mixture converts the first product into methyl ether. The rates of formation of methyl hydrogen sulfate at 40° and 50° and that for methyl ether formation at 100° have been determined[144] by measuring the acid concentrations of the reaction mixtures at suitable intervals. Under the same conditions both reactions proceed more readily than those involving the corresponding ethyl compounds. The temperature coefficient for the rate of formation of methyl hydrogen sulfate was found to be 2.6/10°, while for the ethyl homolog it is 3.0. The presence of water in the reaction mixture greatly retards the formation of both ethers.

At a temperature below 0° sulfur trioxide reacts with methanol to form the acid ester without appreciable side reactions.[145] Chlorosulfonic acid also reacts readily under these conditions, as mentioned earlier.[34]

Methyl hydrogen sulfate has been described[34] as an oily liquid which does not adhere to glass, does not crystallize at −30°, and is miscible with ether in all proportions. The monohydrate, however, is insoluble in ether. Determination of the molecular weight in sulfuric acid solution gave the value 95 instead of the 112 expected if no ionization had occurred.[146] An investigation of the conductivity of the aqueous solution indicates that methyl hydrogen sulfate is as completely ionized as hydrochloric acid.[147]

From a mixture containing two moles of methyl hydrogen sulfate to one of chlorosulfonic acid about one-half mole of methyl chlorosulfonate is obtained[148] when the reaction temperature is 90° to 100°.

$$CH_3HSO_4 + ClSO_3H \rightarrow CH_3OSO_2Cl + H_2SO_4$$

After some time at this temperature the secondary reaction shown below becomes significant.[149]

$$CH_3OSO_2Cl + CH_3HSO_4 \rightarrow (CH_3)_2SO_4 + ClSO_3H$$

Salts of Methyl Hydrogen Sulfate. The salts of methyl hydrogen sulfate have usually been made by adding to the reaction mixture of methanol and sulfuric acid, after dilution with water, the hydroxide or carbonate of a metal of which the sulfate is insoluble in water. The corresponding salts of the ester are all soluble, and from these by addition of a metallic sulfate any desired salt may be obtained.

$$2CH_3HSO_4 + BaCO_3 \rightarrow Ba(CH_3SO_4)_2 + H_2O + CO_2$$

$$Ba(CH_3SO_4)_2 + Na_2SO_4 \rightarrow 2NaCH_3SO_4 + \underline{BaSO_4}$$

A modification of this, which is possible when the lead salt is first formed, is to precipitate the lead as the sulfide with hydrogen sulfide and then neutralize the solution with a carbonate or hydroxide. Methyl ammonium sulfate has been obtained by neutralizing the reaction mixture containing unreacted sulfuric acid with ammonium carbonate,[133] followed by an extraction of the mixture of salts with hot methanol, which dissolves the methyl ammonium sulfate. Ethyl alcohol is not so satisfactory for the separation because of the lower solubility of this salt. Methyl methylammonium sulfate is obtained in high yield by passing ammonia into a solution of methyl sulfate in benzene. Methyl phenylammonium sulfate precipitates from a methanol solution of methyl hydrogen sulfate when aniline is added.[19]

A mixture of equimolecular quantities of potassium methyl sulfate and potassium chloride[150] when heated to a high temperature evolves a gas which is a mixture of one volume of methyl ether to two volumes of methyl chloride. An excess of potassium chloride increases the yield of methyl chloride.

$$2CH_3KSO_4 \rightarrow (CH_3)_2O + K_2S_2O_7$$

$$CH_3KSO_4 + KCl \rightarrow CH_3Cl + K_2SO_4$$

Barium chloride gives a larger yield of methyl chloride than does the potassium compound. Metal bromides behave in a similar manner.

In a study of the determination of methyl groups[151] in sulfur compounds by their decomposition with hydriodic acid, potassium methyl sulfate was found to give low results because of the formation of methanethiol. The formation of this might be accounted for by the following reactions, which, however, require verification.

$$CH_3KSO_4 + HI \rightarrow CH_3I + KHSO_4$$

$$KHSO_4 + 9HI \rightarrow H_2S + KI + 4H_2O + 4I_2$$

$$CH_3I + H_2S \rightarrow CH_3SH + HI$$

Although the second stage in the methylation of phenol with methyl sulfate, the reaction of sodium methyl sulfate with sodium phenoxide, takes place more slowly[152] than the primary reaction, it can be completed by long refluxing of the aqueous solution of the reactants.

$$CH_3NaSO_4 + C_6H_5ONa \rightarrow C_6H_5OCH_3 + Na_2SO_4$$

The hydrolysis of methyl hydrogen sulfate and its salts has received considerable investigation. The hydrolysis of methyl potassium sulfate is an autocatalytic reaction,[153] since the hydrogen-ion concentration increases as the reaction progresses, which in turn accelerates the rate of decomposition. Since potassium hydrogen sulfate is not a strong acid the concentration of the hydrogen ion may be taken as

$$CH_3KSO_4 + H_2O \rightarrow CH_3OH + KHSO_4$$

being proportional to the square root of the bisulfate concentration. On this basis the velocity of the hydrolysis was expressed by the equation $dx/dt = k_2 \sqrt{a} \sqrt{x} (1 - x)$ in which a represents the initial concentration of potassium methyl sulfate and x the amount hydrolyzed at time t. This equation was found to express the results of the hydrolysis at 105° and 115° in a quantitative manner. The presence of methanol in the reaction mixture inhibits the hydrolysis slightly, and the addition of neutral salts such as potassium nitrate produces the opposite effect. Neutral potassium sulfate decreases the reaction velocity by decreasing the hydrogen-ion concentration. Hydrochloric acid produces a large increase in the rate of hydrolysis. The temperature coefficient of the reaction velocity was found to be 2.75/10° in the interval 105–115°.

The hydrolysis of calcium, strontium, and barium methyl sulfates[154] in hydrochloric acid solution has been formulated as follows:

$$Ba(CH_3SO_4)_2 + H_2O \rightarrow \underline{BaSO_4} + CH_3OH + CH_3HSO_4$$

$$CH_3HSO_4 + H_2O \rightarrow CH_3OH + H_2SO_4$$

$$Ba(CH_3SO_4)_2 + H_2SO_4 \rightarrow \underline{BaSO_4} + 2CH_3HSO_4$$

Since the substances involved are all highly ionized the results could be explained much more simply by the following ionic equations:

$$CH_3SO_4^- + H_2O \rightarrow H^+ + SO_4^{--} + CH_3OH$$

$$Ba^{++} + SO_4^{--} \rightarrow \underline{BaSO_4}$$

The rate of hydrolysis in water alone is extremely slow.[155] The rate of the reaction increases with an increase in the atomic weight of the metal in the salt. A study of the hydrolysis reaction in barium hydroxide solution[156] indicates this reaction to be of the second order.

A large number of salts of methyl hydrogen sulfate have been prepared by the usual methods already mentioned, but as they are chiefly of interest in connection with the chemistry of the metals involved they are not considered here.

Methyl Fluorosulfonate. Methyl fluorosulfonate is formed by the action of fluorosulfonic acid with methanol. It is a liquid which boils at 92°[157] and has d^{16} 1.427. It corrodes glass and in the presence of alkali converts phenol into anisole.

Methyl Chlorosulfonate. Methyl chlorosulfonate has been prepared in 70% yields from methyl sulfate and chlorosulfonic acid[148] and in small amounts from methyl hydrogen sulfate with the same reagent.

$$(CH_3)_2SO_4 + ClSO_3H \rightarrow CH_3OSO_2Cl + CH_3HSO_4$$

$$CH_3HSO_4 + ClSO_3H \rightarrow CH_3OSO_2Cl + H_2SO_4$$

Probably the most satisfactory method, however, is by the action of sulfuryl chloride upon methanol[158] at a low temperature,

$$CH_3OH + SO_2Cl_2 \rightarrow CH_3OSO_2Cl + HCl$$

preferably in carbon tetrachloride solution, the hydrogen chloride being removed by a current of dry air.[48] Other methods of preparation that have been used include the action of methyl chloroformate upon chlorosulfonic acid[159] and the reaction of methyl hypochlorite with

$$ClCOOCH_3 + ClSO_3H \rightarrow CH_3OSO_2Cl + CO_2 + HCl$$

sulfur dioxide.[160]

$$CH_3OCl + SO_2 \rightarrow CH_3OSO_2Cl$$

The pure acid chloride is a colorless liquid which distils at 42°/16 mm. and at 134–135°/760 mm. without decomposition;[148] it has the d_4^0 1.514 and d_4^{15} of 1.492; and it melts at −70°. It was reported to have a violent lachrymatory action.

The reaction of methyl chlorosulfonate with water[161] in the presence of methanol has been studied in detail. Complete hydrolysis gives methanol, hydrochloric, and sulfuric acids. When water is present in excess, methyl hydrogen sulfate and hydrochloric acid are the principal primary products, whereas with increasing quantities of methanol,

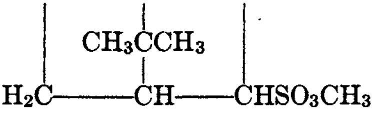
$$CH_3OSO_2Cl + H_2O \rightarrow CH_3HSO_4 + HCl$$

methyl chloride formation occurs to a considerable extent.

$$CH_3OSO_2Cl + CH_3OH \rightarrow CH_3Cl + CH_3HSO_4$$

A little methyl ether is also found among the reaction products.

Under the trade name Vaillantite methyl chlorosulfonate has been recommended[162] as a methylsulfonating agent. With benzene, toluene, chlorobenzene, and naphthalene it gives about 60% yields of the methyl sulfonate, together with some of the sulfonic acid and traces of the sulfone. It reacts with camphor to form an addition product which decomposes to give methyl 3-camphorsulfonate. This is soluble in alkali, probably as the enol form. The acid obtained from this ester



is different from the two previously known sulfonic acids of camphor.

In the presence of zinc chloride at 140–160° methyl acetate reacts with methyl chlorosulfonate[163] according to the following equation.

$$CH_3COOCH_3 + CH_3OSO_2Cl \rightarrow CH_3COOCH_2SO_3CH_3 + HCl$$

The yield of methyl acetoxymethanesulfonate is 25–30%.

Methyl chlorosulfonate is an active methylating agent. In 30% sodium hydroxide solution phenol is converted into anisole[164] in 75% yields. With dialkylamines a derivative of a tertiary amine is formed.[165]

$$CH_3OSO_2Cl + 2(CH_3)_2NH \rightarrow (CH_3)_3NSO_3 + (CH_3)_2NH_2Cl$$

(For other alkylating reactions of this type of compound see the ethyl homolog.)

Chloromethyl chlorosulfonate has been obtained[166] from paraformaldehyde and chlorosulfonic acid in a yield of 135 g. from 100 g. of the polymer, and also by the action of chlorosulfonic acid upon chloromethyl chloroformate.[159]

$$HCHO + 2ClSO_3H \rightarrow ClCH_2OSO_2Cl + H_2SO_4$$

$$ClCH_2OOCCl + ClSO_3H \rightarrow ClCH_2OSO_2Cl + CO_2 + HCl$$

Its solubility in water is so slight that hydrolysis is slow even in sodium hydroxide solution. It possesses a penetrating odor and is irritating to the mucous membranes. The boiling point was given as 49–50°/14 mm. and the density as 1.63.

Preparation of Ethyl Hydrogen Sulfate. The reaction of ethyl alcohol with sulfuric acid was one of the first organic reactions to be studied, undoubtedly because of the ready availability of both reactants. The earlier somewhat controversial literature[167] is quite voluminous and can only be listed here. Hennell[167] found that equal weights of alcohol and "oil of vitriol" resulted in a 56% conversion of the acid into ethyl hydrogen sulfate. Berthelot[168] reported that at steam-bath temperature with 94% alcohol and 95% acid, 59% esterification was obtained in twenty days. In the light of later work the slow change noted over this long period was due to secondary reactions rather than the formation of the acid ester. The reaction between three moles of absolute alcohol and one of sulfuric acid was reported to give a 77% esterification of the acid.[34a] The equilibrium was found to change very little with change in temperature. A more careful investigation[169] of this reaction over the temperature range of 22° to 96° gave 1.70 as the average value for the equilibrium constant, $K = \frac{[C_2H_5HSO_4]\,[H_2O]}{[C_2H_5OH]\,[H_2SO_4]}$, when titration was used to determine the extent of the reaction, and 1.74 when the unreacted sulfuric acid was precipitated as lead sulfate and this compared with the lead ethyl sulfate still in solution. Since the two results agreed within the experimental error the formation of ethyl sulfate and other secondary reaction products was considered to be negligible over the range of conditions investigated. When attempts were made to calculate the equilibrium constant, assuming hydrate formation for the water present, unsatisfactory results were obtained. Reaction-velocity measurements indicated the reaction to be of the second order with a temperature coefficient of 3.0 per 10°, which is slightly higher than that for methanol. The formation of ethyl hydrogen sulfate from 99.9% alcohol and 95% sulfuric acid was found [170] to have reached its equilibrium value in 150 minutes at 20° and in 10 minutes or less at 70°. This rapid reaction is followed by a very slow change in acidity due to secondary changes which were not investigated. By isolation of potassium ethyl sulfate from various reaction mixtures it was shown that the determination of the extent of ethyl hydrogen sulfate formation by titration gave accurate values for temperatures under 80°. With nearly equimolecular quantities of reactants the extent of ester formation is between 58 and 60% over the temperature range of 20° to 70°. This is considerably higher than Kremann's value.

An investigation of the variation of the equilibrium constant with the change in the molar ratio of alcohol to 100% sulfuric acid [171] gave 1.52 for a 4 to 1 ratio and 1.73 for a 0.5 to 1 ratio. Molar ratios above and below these values give rapidly changing values of K. In a solution containing fourteen or more moles of alcohol to one of sulfuric acid the reaction is very slow, from two to three weeks being necessary to attain equilibrium at 18°. With the alcohol present in large excess the reaction is apparently monomolecular.

The formation and decomposition of ethyl hydrogen sulfate in aqueous solution has been carefully investigated.[172] By assuming that the sulfuric acid existed as a dihydrate a more satisfactory equilibrium constant was obtained, the ethyl hydrogen sulfate being left unhydrated. The presence of water decreases [173] considerably the velocity of the ester formation. Kailan devised a complex empirical formula to fit the data. The addition of hydrochloric acid to the reaction mixture was found to increase the rate of ester formation but not so much as would be expected from the increase in concentration of the hydrogen ions.

Marchand [174] attempted to isolate pure ethyl hydrogen sulfate from the alcohol-sulfuric acid reaction mixture and obtained a liquid having the density 1.316 at 17°. Barium ethyl sulfate was treated with the theoretical amount of sulfuric acid in aqueous solution and the filtrate evaporated over calcium chloride. This product probably still contained a small amount of water.

In a more recent[175] attempt to prepare the pure ester the best sample had an ethyl hydrogen sulfate content of 84.5%. Further concentration was impossible owing to decomposition. From the solubility behavior of this product it was calculated that the pure ester would dissolve in dry ether to the extent of 1.27 g. per 100 ml. at 30°. This low solubility seems doubtful, however, since Claësson[34a] described the same compound as an oily ether-soluble compound which becomes immiscible with ether when it is mixed with an equimolecular quantity of water. Probably more satisfactory methods of obtaining the pure ester are the reaction of sulfur trioxide upon anhydrous alcohol[145] or the action of ethyl sulfate upon an excess of alcohol,[176] followed by removal of the unreacted alcohol and the ether under reduced pressure at a temperature below 40°.

$$(C_2H_5)_2SO_4 + C_2H_5OH \rightarrow (C_2H_5)_2O + C_2H_5HSO_4$$

The reaction between ethylene and sulfuric acid has been thoroughly studied because of its commercial importance in the preparation of the two esters of sulfuric acid and the alcohol and ether resulting from their hydrolysis. The presence of ethylene in various gaseous fuels and in the gas obtained by the cracking of oil in petroleum refining provides a large supply of raw material. The first investigators[177a, b, c] of this reaction observed that ethylene reacts very slowly with concentrated sulfuric acid at ordinary temperatures but that at 100° and above absorption of the gas takes place rapidly. However, if the temperature is much above 110–120° appreciable charring occurs,[177d] and side reactions are detectable at even lower temperatures.

The amounts of ethylene absorbed from gases whose ethylene content was varied have been determined[178] for several concentrations of sulfuric acid at 50° and 70°. Three stages in the process were identified: (1) the solution of the ethylene in the sulfuric acid; (2) the formation of ethyl hydrogen sulfate; (3) the formation of ethyl sulfate. It has already been mentioned (see p. 9) that it is probable that reaction occurs in the thin surface film under most conditions rather than in the body of the liquid, hence stage 1 does not involve diffusion of the ethylene away from the gas-liquid interface. Gaseous mixtures containing 69% or more ethylene all gave about the same amount of absorption in 99.3% sulfuric acid at 50°. These results are shown in Table IV. The results are empirical and vary with the type of absorption vessel. The effects of varying the concentration of the acid and the temperature upon the products formed are shown in Table V. The presence of ethyl hydrogen sulfate was found to have a decided autocatalytic effect upon the reaction rate, which was explained on the basis of an increased solubility of the ethylene in the mixture.

TABLE IV

% Ethylene in Gas	% Gain in Weight of 99.3% H_2SO_4	% Ethylene in Gas	% Gain in Weight of 99.3% H_2SO_4
92.7	3.66	50.7	2.62
86.4	3.87	46.4	2.30
84.0	3.58	41.4	2.21
78.9	3.62	37.3	1.91
72.7	3.58	29.6	1.44
69.6	3.52	25.2	1.32
64.6	3.41	17.9	1.06
59.8	3.14	8.0	0.48
57.3	2.72		

Rapid agitation of the absorption mixture increases the absorption rate greatly,[179] owing to increased surface area exposed to the ethylene. The same investigators reported that at temperatures above 60° a partial decomposition of the products in side reactions occurred.

TABLE V

% H_2SO_4 at Beginning	Weight Increase, %	$C_2H_5HSO_4$ Formed	$(C_2H_5)_2SO_4$ Formed	% H_2SO_4 at End	% H_2O at End	Temperature, °C
93.1	16.56	60.1	0.0	33.9	6.0	50
97.6	29.23	73.9	15.8	8.4	1.9	50
99.3	32.01	72.7	22.2	4.6	0.5	50
93.1	20.83	69.5	2.2	22.5	5.8	70
95.8	27.98	79.1	9.4	8.2	3.3	70
98.1	34.25	74.8	20.3	3.5	1.4	70
98.8	36.23	68.1	29.3	1.7	0.9	70
100.1	36.62	70.0	30.0	....	...	70

The presence of various salts increases the rate of absorption, cuprous sulfate and chloride being the most useful; the concentration of catalyst was between 1 and 5% for low-temperature absorption. By the addition of 5% cuprous oxide to 95% sulfuric acid a 94% yield of ethyl hydrogen sulfate was obtained at 40°, the ethylene absorption occurring rapidly. The ethylene was absorbed at even lower temperatures in the presence of a cuprous catalyst and mercury. Cupric sulfate also is an effective catalyst.[180a] In outlining a process for the removal of ethylene from illuminating gas[180b] a catalyst consisting of 1% of mercury with vanadic, uranic, or molybdic acid was suggested for use in 66 Bé. acid. In the presence of a foam-producing agent colloidal silver and silver compounds[181] are also effective. When catalysts are used the temperature of the reaction mixture can be kept as low as 35°, preventing the formation of isethionic acid. A semicommercial plant has been described[182] in which a copper catalyst is employed. More recently[183] several other catalysts have been advocated for accelerating the absorption process. Catalysts only increase the absorption rate, however, and do not affect the total absorption.[184]

A study of the effect of pressures above atmospheric[185] upon the reaction of ethylene with 100% sulfuric acid showed that at 3.5 atmospheres and ordinary temperature the product contained a 35% yield of ethyl sulfate and 51% of ethyl hydrogen sulfate, and at 10 atmospheres the percentages were 62 and 30. This is important in the preparation of alcohol.[94] At 15 atmospheres pressure 2 kg. of sulfuric acid is needed per kilogram of alcohol (from hydrolysis of the resulting esters), whereas at atmospheric pressure 5 kg. is necessary. For details of various absorption procedures the monograph of Ellis[186] should be consulted.

At low temperatures ethers are only slightly reactive toward concentrated sulfuric acid, but upon long heating ethyl ether is decomposed[187] with the formation of ethyl hydrogen sulfate.

Ethyl acetate and ethyl chloroacetate[188] are decomposed by 100% sulfuric acid to the extent of 15.3 and 32.9% respectively on a comparable basis according to the following equation.

$$RCOOC_2H_5 + H_2SO_4 \rightarrow RCOOH + C_2H_5HSO_4$$

Reactions of Ethyl Hydrogen Sulfate. The hydrolysis of ethyl hydrogen sulfate to the alcohol and acid or the partial hydrolysis of a reaction mixture followed by conversion to ethyl ether[186,189] by the usual reaction has received some investigation and offers a method for the partial utilization of the ethylene obtained from petroleum refining. Ethyl alcohol presumably from this source has been competing with that from the regular fermentation process for some time. The hydrolysis takes place with considerable difficulty at ordinary temperatures. For instance, it has been reported[190] that a dilute solution of ethyl hydrogen sulfate does not undergo measurable hydrolysis after standing 24 hours at room temperature. At 100°, however, reaction occurs readily in concentrated solutions. The rate of hydrolysis of the soluble barium salt has been measured[191] by the rate at which barium sulfate is precipitated. It was found to be greater in 1 *N* hydrochloric acid than in water but less in 0.5 *N* acid than in water solution. This result, however, was not confirmed by other workers,[192] who found the rate to increase regularly with increase in the hydrogen-ion concentration. The rate of hydrolysis in an alkaline solution is in general less than in an acid solution of the same concentration. The rate of hydrolysis of the various salts increases with an increase in the atomic weight of the metal while a change in weight of the alkyl group has the opposite effect.[156]

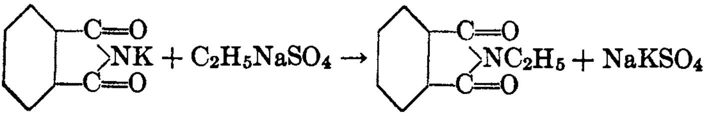
The hydrolysis of barium ethyl sulfate was said by Kremann to be a first-order reaction, but this statement was criticized by Linhart,[156] the hydrolysis of this salt with barium hydroxide or of the sodium salt with sodium hydroxide taking place in accordance with a second-order reaction equation.

In addition to the general reactions already given (see p. 15), salts of ethyl hydrogen sulfate have been employed in several other types of alkylations. Heating sodium ethyl sulfate to 120–130° with a concentrated solution of sodium sulfite[193] results in a nearly quantitative yield of sodium ethanesulfonate.

$$C_2H_5NaSO_4 + Na_2SO_3 \rightarrow C_2H_5SO_3Na + Na_2SO_4$$

By fusing the sodium salt of an amide or potassium phthalimide with sodium ethyl sulfate the N-ethyl compounds are formed in good yields.[194] Sodium amide behaves similarly, forming ethylamine mixed with some ammonia.

$$CH_3CONHNa + C_2H_5NaSO_4 \rightarrow CH_3CONHC_2H_5 + Na_2SO_4$$



$$NaNH_2 + C_2H_5NaSO_4 \rightarrow C_2H_5NH_2 + Na_2SO_4$$

Alcoholic ammonia reacts with potassium ethyl sulfate at a high temperature to give some ethylamine.[195] Distillation of a mixture of barium ethyl sulfate and ammonium sulfate also gives a small amount of this product.[196] The ethylation of conine, diethylamine, and di-*n*-propylamine to the tertiary amines proceeds slowly[197] at 100° in a concentrated solution of potassium ethyl sulfate.

$$2(C_2H_5)_2NH + C_2H_5KSO_4 \rightarrow (C_2H_5)_3N + (C_2H_5)_2NH_2KSO_4$$

By heating a concentrated aqueous solution of sodium ethyl sulfate with sodium phenoxide in an autoclave at 150° for an hour a high yield of phenetole is obtained.[198] Similar attempts to ethylate *o*- and *p*-nitrophenols sometimes led to explosions.

Distillation of potassium ethyl sulfate with potassium nitrate[199] was reported to give a sweet-tasting liquid which distils at 84–86° and has the d^{20} of 1.045. It exploded when heated above its boiling point. Despite the analytical results, which indicated an empirical formula of $C_6H_{14}O_7N_2$, the product was probably mostly ethyl nitrate; this boils at 84–86° and has the d^{20} of 1.020.

At 25° sodium ethyl sulfate reacts very slowly with hydrogen chloride,[200] but at 65° or above a quantitative yield of ethyl chloride results. The barium salt behaves similarly at 80°.

$$C_2H_5NaSO_4 + HCl \rightarrow NaHSO_4 + C_2H_5Cl$$

The solution of an arylhydroxylamine in alcoholic sulfuric acid undergoes a series of complex reactions among which is the alkylation of an intermediate phenol to a phenol ether.[201]

The electrolysis of a solution of ethyl hydrogen sulfate does not produce acetaldehyde as one of the products.[202]

A very large number of salts of ethyl hydrogen sulfate have been described in the literature, but since these are primarily of interest from the standpoint of the respective metals they are not considered here.

Ethyl Halosulfonates. Fluorosulfonic acid reacts readily with ethylene[203] and also with ethyl ether[157] with formation of ethyl fluorosulfonate.

$$C_2H_4 + FSO_3H \rightarrow C_2H_5OSO_2F$$

The yields obtained corresponded to 40 and 30% of the theoretical amounts. It is a colorless liquid which distils at 24°/12 mm., 113°/752 mm., and has *d* 1.310 at "room temperature." Although fluorosulfonic acid does not affect glass the esters have an appreciable etching effect. Ethyl fluorosulfonate is not miscible with water but hydrolyzes quite readily, and the products, of course, dissolve. No action was noted with absolute ethyl alcohol, which is surprising in view of the vigorous reaction of ethyl chlorosulfonate with this compound. Since the methyl fluorosulfonate exerts an alkylating action toward phenol in alkaline solution the ethyl homolog undoubtedly would also, but this reaction has not been investigated.

Ethyl chlorosulfonate was first obtained by the action of fuming sulfuric acid upon ethyl chloride,[204] isethionic acid resulting as a by-product of the reaction. From 2 kg. of sulfur trioxide Purgold [204c] obtained 600 g. of ethyl chlorosulfonate. He prepared the same sub-

$$C_2H_5Cl + SO_3 \rightarrow C_2H_5OSO_2Cl$$

stance by the action of phosphorus pentachloride upon potassium ethyl sulfate, and from ethyl chlorocarbonate and sulfur trioxide.

$$C_2H_5OSO_2OK + PCl_5 \rightarrow C_2H_5OSO_2Cl + KCl + POCl_3$$
$$ClCOOC_2H_5 + SO_3 \rightarrow C_2H_5OSO_2Cl + CO_2$$

Ethyl hydrogen sulfate also reacts with phosphorus pentachloride [205] to give the same product. Sulfur dioxide adds to ethyl hypochlorite.[160] Sulfuryl chloride reacts readily with absolute alcohol to give an 80%

$$C_2H_5OCl + SO_2 \rightarrow C_2H_5OSO_2Cl$$

yield of the acid chloride [158, 206] if a stream of dry air is bubbled through the reaction mixture. Ethylene dissolves very readily in a mixture of sulfuric and chlorosulfonic acids [207] with the evolution of heat to give a high yield of the acid chloride. An excess of chloro-

$$C_2H_5OH + SO_2Cl_2 \rightarrow C_2H_5OSO_2Cl + HCl$$
$$C_2H_4 + ClSO_3H \rightarrow C_2H_5OSO_2Cl$$

sulfonic acid reacts with ethyl alcohol [34a] to give the acid chloride when the reaction mixture is not kept at a low temperature.

$$2ClSO_3H + C_2H_5OH \rightarrow C_2H_5OSO_2Cl + H_2SO_4 + HCl$$

Ethyl chlorosulfonate is a colorless mobile liquid boiling at 58°/20 mm. and having the $d^{18} = 1.263$. It has a penetrating odor and is a strong lachrymator. It is insoluble in water but dissolves in fuming nitric acid, from which it is precipitated unchanged by dilution of the solution with water.

When distilled at atmospheric pressure it decomposes into sulfur dioxide, sulfuric acid, hydrogen chloride, and ethylene. Reaction is slow with cold water but becomes quite rapid at the boiling point of the mixture. In a closed tube at 100° the products are ethyl ether and sulfuric and hydrochloric acids.[204c] When distilled with steam a 16% yield of ethyl chloride is evolved. No trace of ethyl hydrogen sulfate was found.[207a] With concentrated potassium hydroxide in water or alcohol solution ethyl chloride and potassium sulfate result.

$$C_2H_5OSO_2Cl + 2KOH \rightarrow C_2H_5Cl + K_2SO_4 + H_2O$$

The reaction with an alcohol is very vigorous, a variety of products resulting. The probable reactions are listed below.

$$C_2H_5OSO_2Cl + i\text{-}C_5H_{11}OH \rightarrow C_2H_5Cl + i\text{-}C_5H_{11}HSO_4$$

$$C_2H_5OSO_2Cl + C_2H_5OH \rightarrow C_2H_5Cl + C_2H_5HSO_4$$

$$C_2H_5OSO_2Cl + 2C_2H_5OH \rightarrow (C_2H_5)_2O + HCl + C_2H_5HSO_4$$

$$C_2H_5OSO_2Cl + C_2H_5OH \rightarrow (C_2H_5)_2SO_4 + HCl$$

Some of the ethyl ether may also result from another reaction.

$$(C_2H_5)_2SO_4 + C_2H_5OH \rightarrow (C_2H_5)_2O + C_2H_5HSO_4$$

The yield of ethyl sulfate was never above 20% of the theoretical. Ethyl chlorosulfonate has also been reported to react with ethyl ether,[206a] but this is contrary to earlier work [207a] and should be reinvestigated. With a sodium alcoholate in ether solution an addition product results whose structure [206] has probably not been satisfactorily explained. This addition product decomposes when its ether solution is heated, or upon the addition of water, into the alkyl sulfate, alkyl ether, sodium alkyl sulfate, and sodium sulfate. The yields of the various products determined are given in Table VI. The reaction is thus seen to be similar to that with the alcohols themselves.

TABLE VI

YIELDS OF DECOMPOSITION PRODUCTS

Products	C_2H_5OH	$i\text{-}C_3H_7OH$	$i\text{-}C_4H_9OH$	$i\text{-}C_5H_{11}OH$
$C_2H_5RSO_4$, %	37.2	62.2	50	49
C_2H_5OR, %	27.7	....	..	Present
$RNaSO_4$, %	47.6	29.3	26	29
Na_2SO_4, %	5	....	11	21.8

Ethyl chlorosulfonate reacts violently with ammonia [204c, 208] to give a mixture of products. When dry ammonia is passed into the dry ether solution of the acid chloride most of the products precipitate as deliquescent salts. In the ether solution a trace of triethylamine and an oil which was probably $C_2H_5NHSO_2OC_2H_5$ were found.[209] In another experiment using benzene as the solvent the analogous compound $(C_2H_5)_2NSO_2OC_2H_5$ was isolated from the benzene layer. The precipitated salts consist of a mixture of di-, tri-, and tetraethylammonium chlorides. No ethylammonium chloride was present. In addition there was some ammonium chloride and ammonium aminodisulfonate; the latter readily hydrolyzes to ammonium bisulfate and ammonium sulfamate. With an excess of ammonia the principal product becomes ethylamine.[210a] The chief action of the ethyl chlorosulfonate is therefore that of an alkylating agent.

Diethylamine[209] in cold ether solution gives chiefly diethylaminosulfonic acid, $(C_2H_5)_2NSO_3H$, together with some triethylamine and tetraethylammonium chloride. It was shown by the preparation and study of ethyl diethylaminosulfonate that this compound is not an intermediate since it was inert under the same conditions. Di-*n*-butylamine[210b] at 100° reacts with ethyl and other chlorosulfonates with evolution of the alkyl chloride.

The reaction of ethyl chlorosulfonate with aniline has been investigated quite completely. It was first[211] reported that ethyl chloride and sulfanilic acid were the only products. However, it was soon[212] found that phenylaminosulfonic acid was an intermediate in the formation of the sulfanilic acid. If ethyl chlorosulfonate is added to an ether solution of aniline at a low temperature[124] neither sulfanilic acid nor ethyl chloride results. The products are N-ethylaniline hydrochloride, aniline hydrochloride, and phenylaminosulfonic acid. Later[210] work has shown that diethylaniline and ethylphenylaminosulfonic acid are also present in the reaction products. The last named product can be further alkylated with ethyl chlorosulfonate.

$$C_6H_5N(C_2H_5)SO_3Na + ClSO_2OC_2H_5 \rightarrow C_6H_5N(C_2H_5)_2 + NaCl + ?$$

With dimethylaniline in chloroform solution at a low temperature, ethyl chlorosulfonate forms ethyl chloride and an addition product of dimethylaniline with sulfur trioxide, together with dimethylethylphenylammonium chloride. The first equation accounts for about 80% of

$$ClSO_2OC_2H_5 + 2C_6H_5N(CH_3)_2 \rightarrow C_6H_5N(CH_3)_2SO_3 + C_2H_5Cl$$

$$ClSO_2OC_2H_5 + 2C_6H_5N(CH_3)_2 \rightarrow C_6H_5N(CH_3)_2C_2H_5Cl + C_6H_5N(CH_3)_2SO_3$$

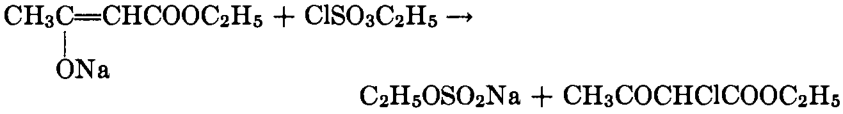
the reaction products. The sulfur trioxide addition product when heated to 60° rearranges into the *p*-sulfonic acid, a compound also formed in the reaction of ethyl chlorosulfonate upon dimethylaniline at a higher temperature. The quaternary salt is not produced by the action of ethyl chloride on dimethylaniline since these do not react appreciably at a low temperature.

At 60° a mixture of phenol and ethyl chlorosulfonate reacts[204a] to give ethyl chloride, hydrogen chloride, two sulfonic acids, and a viscous aromatic oil. Sodium phenoxide (50 g.) in ether suspension gives 22 g. of phenetole and 24 g. of phenol when treated with 31 g. of ethyl chlorosulfonate. The ether-insoluble residue contains sodium chloride and sodium bisulfate. It is stated in the patent literature[213] that an alkaline solution of eugenol or other substituted phenol reacts with ethyl chlorosulfonate to give a mixed aryl alkyl sulfate. However, the properties of the compounds reported correspond more nearly to the ethyl ethers than the esters of the phenols, so it is probable that the interpretation of the reaction in the patents is in error.

The reaction of ethyl chlorosulfonate with a concentrated water solution of sodium acetate[204c] gives ethyl acetate and acetic acid.

$$C_2H_5OSO_2Cl + 2CH_3COONa + H_2O \rightarrow CH_3COOC_2H_5 + CH_3COOH + NaCl + NaHSO_4$$

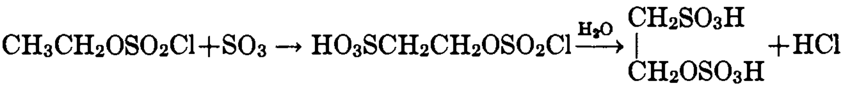
Since ethyl chlorosulfonate behaves as an alkylating agent so frequently, it is surprising that it does not do so with the sodium salts of ethyl acetoacetate and ethyl malonate. Instead, chlorination occurs exclusively, the other product being a sulfite. The reaction was carried out in dry ether at a low temperature.



$$CH_3\underset{\displaystyle ONa}{\underset{|}{C}}{=}CHCOOC_2H_5 + ClSO_3C_2H_5 \rightarrow C_2H_5OSO_2Na + CH_3COCHClCOOC_2H_5$$

The final product with ethyl malonate under similar conditions was ethanetetracarboxylic acid ester, presumably formed from ethyl chloromalonate and ethyl sodiomalonate.[206b]

Ethyl chlorosulfonate is sulfonated by sulfur trioxide to a compound[207a] which is readily hydrolyzed to isethionic acid.



$$CH_3CH_2OSO_2Cl + SO_3 \rightarrow HO_3SCH_2CH_2OSO_2Cl \xrightarrow{H_2O} \begin{array}{l} CH_2SO_3H \\ | \\ CH_2OSO_3H \end{array} + HCl$$

With fuming hydrochloric acid a 91% yield of ethyl chloride is obtainable, and hydrobromic acid gives up to 50% of ethyl bromide.[210]

When ethyl chlorosulfonate is treated with a suspension of zinc dust in water a violent reaction ensues, ethyl chloride is evolved, and zinc sulfite remains in solution. When heated to 130° with tin and a trace of iodine, ethylene, stannic chloride, sulfur dioxide, and hydrogen chloride are produced.[206b]

$$ClSO_3C_2H_5 + Zn \rightarrow C_2H_5Cl + ZnSO_3$$

When chlorine is passed into bis-(2-chloroethyl) sulfite 2-chloroethyl chlorosulfonate results[214a] in 90% yields. It has also been obtained from ethylene chloride and sulfur trioxide.[214b] The corresponding bromo compound has been prepared from bis-(2-bromoethyl) sulfite and sulfuryl chloride[215] in a yield of 81%.

n-Propyl Hydrogen Sulfate. Apparently no attempt has been made to isolate the free ester. The potassium salt[216] has been prepared in the usual way from the reaction mixture obtained from *n*-propyl alcohol and sulfuric acid. The optical properties[217] of the crystalline salt have been measured. The conductivities[218] of solutions of the sodium salt and the free acid indicate that they are highly ionized.

n-Propyl chlorosulfonate[219] results in 70% yields by the action of sulfuryl chloride upon the alcohol at a low temperature. It is a liquid which distils at 44°/4 mm. and 65°/15 mm. With *n*-propyl nitrite at 80° a 32% yield of the alkyl sulfate is obtained.[219b]

n-Butyl Hydrogen Sulfate. Barium *n*-butyl sulfate has been prepared[220] from the *n*-butyl alcohol and sulfuric acid reaction mixture by neutralizing with barium carbonate. The ammonium salt may be made[221] by heating *n*-butyl alcohol with ammonium aminodisulfonate, $NH(SO_3NH_4)_2$, in pyridine solution.

n-Butyl chlorosulfonate has been obtained[215] from *n*-butyl sulfite and chlorine in 96% yield, and also from the alcohol and sulfuryl chloride. Attempts to prepare it by the action of excess chlorosulfonic acid upon the alcohol have been unsuccessful.[222] *n*-Butyl chlorosulfonate has the following properties: B.p. 76–77°/13 mm., $d = 1.250$, $d_0^{22} = 1.225$, and $n_D^{23.1}$ of 1.4245. It reacts with *n*-butyl orthoformate and with *n*-butyl sulfite to give *n*-butyl sulfate.

$$(n\text{-}C_4H_9)_2SO_3 + Cl_2 \rightarrow n\text{-}C_4H_9OSO_2Cl + n\text{-}C_4H_9Cl$$

Isobutyl Hydrogen Sulfate. The pyrolysis of some salts of this compound have already been mentioned. The statement that the barium salt decomposes as low as 130° with formation of 2-butene[228] as well as isobutylene is of considerable interest. The potassium salt with potassium ethoxide gives isobutyl ethyl ether when heated in alcohol at 110–130°. Calcium isobutyl sulfate has been described.[224]

Isobutyl chlorosulfonate[158] has been obtained in a crude state by the action of sulfuryl chloride upon the alcohol, but it was too unstable to purify.

Primary Amyl Hydrogen Sulfates. The earlier investigations of the amyl alcohols from fusel oil did not distinguish between the two isomeric compounds present, hence many of the derivatives recorded in the literature are mixtures. From the action of sulfuric acid on the mixed alcohols[225] a syrupy sulfuric acid derivative was obtained from which a large number of salts were prepared. The free acid was found to be unstable. Chlorine reacted readily with its aqueous solution at ordinary temperatures, but no reaction products were isolated. Nitric acid was also observed to react when warmed with the mixed amyl hydrogen sulfates. It was shown by Pasteur[226] that the two amyl hydrogen sulfates formed isomorphous salts, but that the barium *act*-amyl sulfate was about 2.5 times as soluble in water as the isoamyl salt, the latter being obtained pure after fifteen or twenty recrystallizations of the mixture. This barium isoamyl sulfate was later compared with that obtained from synthetic isoamyl alcohol and the two found to be identical.[227] The solubility of the anhydrous salt was reported to be 9.7 g. per 100 g. of water at room temperature. A more careful study[228] of the separation of the barium amyl sulfates demonstrated the possibility of obtaining both salts in a pure state. From 700 g. of mixed salts obtained from an alcohol containing 80% of the isoamyl compound there was isolated 200 g. of pure isoamyl alcohol. To obtain the optically active isomer it was more convenient to start with a mixture containing 50% or more of the active alcohol which was available in the fusel oil from molasses. The solubility of the barium isoamyl sulfate at 20.5° was given as 12.8 g. per 100 g. of water, while for the *act*-amyl compound it is 28.2 g. per 100 g. of water. Careful determinations were also made of the solubilities of the mixed crystals containing the two salts in varying proportions.

Sodium isoamyl sulfate is listed by Neuberg[229] as one of the substances whose water solutions show hydrotropic properties, and its use as a solvent for casein has been patented.[230]

The rate at which isoamyl sodium sulfate hydrolyzes[231] in acid solution is about half as great as for the ethyl ester. Heating isoamyl potassium sulfate with potassium nitrate is reported[232] to give a considerable amount of the nitrite.

Isopropyl Hydrogen Sulfate. The importance of isopropyl hydrogen sulfate lies in its use as an intermediate in the preparation of isopropyl alcohol and ether from propylene. This olefin reacts much more readily with sulfuric acid than does ethylene,[176, 178] and it can be absorbed in acid of lower concentration. This is necessary to obtain a high yield of the ester, as with concentrated acid side reactions[233] become prominent. Absorption is facilitated by the use of an inert liquid solvent[234] to dissolve the propylene, the solution being kept in contact with sulfuric acid. This decreases the polymerization which occurs if the propylene dissolves directly. Acid of 87% concentration is most satisfactory. Polymerization may also be avoided by the use of 65–80% acid, a temperature of 10–30°, and a pressure of more than 50 lb. per sq. in.[235] The reaction may also be carried out in the liquid phase at a low temperature,[236] the evaporation of a part of the propylene controlling the temperature of the reaction mixture. It is also claimed that propylene will dissolve in concentrated sulfuric acid at −15° if a mixture of gases containing it is kept in contact with the acid for some time.[237] Sulfuric acid diluted with about an equal volume of glacial acetic acid dissolves propylene and forms isopropyl hydrogen sulfate [238] at 40°. This then reacts to give isopropyl acetate.[239]

Isopropyl hydrogen sulfate has also been obtained from the action of concentrated sulfuric acid upon the alcohol,[240] but with this reagent polymers and probably some isopropyl ether represent a considerable share of the reaction products.[20]

For a discussion of the preparation of isopropyl alcohol on a commercial scale from isopropyl hydrogen sulfate Ellis' treatise [186] should be consulted.

Barium isopropyl sulfate loses its water of hydration upon standing in the air.[240]

***sec*-Butyl Hydrogen Sulfate.** The ester obtained from *sec*-butyl alcohol and concentrated sulfuric acid [241] has been used to obtain the optical isomers of the alcohol. The brucine salts were fractionally crystallized. The alcohol obtained upon hydrolysis, however, had a very low rotation, and it was believed that partial racemization had occurred.

Since the butylenes are more readily absorbed than propylene and ethylene it is possible to prepare a mixture of butyl hydrogen sulfates [242] practically free from lower homologs by using the proper concentration of sulfuric acid in the absorption vessel. Isobutylene can be separately absorbed by 65% acid [243] and the other butylenes taken up in 85% acid at 30°, or in not less than 88% acid at 3° or below.[244] The liquid-phase absorption of the butylenes under pressure at 30–35° has also been patented.[245] With 78% sulfuric acid the formation of polymers from liquid 2-butene is very slight, but with higher concentrations this becomes important.[233] Hydrolysis of the butyl hydrogen sulfate obtained from 1- or 2-butene gives *sec*-butyl alcohol.[246]

Higher *sec*-Alkyl Sulfates. The hydrogen sulfates of 3-hexanol [247] and of 2-octanol [248] have been prepared in the usual manner by the action of sulfuric acid on the alcohols. The former ester was found to hydrolyze readily with hydrochloric acid and to give an olefin at a comparatively low temperature.

The octadecyl sodium sulfate which was reported [231] to hydrolyze more readily than the lower alkyl esters was probably a secondary alkyl derivative. Reference has already been made [98] to the technical interest in the esters of various branched-chain secondary alcohols because of their value as wetting agents.

Tertiary alkyl esters of sulfuric acid have apparently not been isolated, but there is some evidence[249] for believing that they may exist as intermediates in the formation of certain mixed ethers. Triphenylcarbinyl hydrogen sulfate apparently exists chiefly in the ionic state in sulfuric acid solution as already mentioned (see p. 2).

SUBSTITUTED ALKYL HYDROGEN SULFATES

Halogen Compounds. Until recently β-chloroethyl hydrogen sulfate has been prepared only in connection with the equilibrium studies already discussed (see p. 4). It has now been obtained from the action of ethylene chlorohydrin with sulfamic acid.[250] The corresponding acid chloride[251] results from the action of sulfuryl chloride[252] upon ethylene chlorohydrin and from the action of sulfur trioxide upon ethylene chloride[253] below 45°.

$$ClCH_2CH_2Cl + SO_3 \rightarrow ClCH_2CH_2OSO_2Cl$$

It is a liquid boiling at 101°/23 mm. It reacts with β-chloroethyl nitrite to give the alkyl sulfate.

$$ClCH_2CH_2ONO + ClCH_2CH_2OSO_2Cl \rightarrow (ClCH_2CH_2)_2SO_4 + NOCl$$

Upon long standing, decomposition occurs with evolution of hydrogen chloride and darkening. It has the odor of chloropicrin. It is apparently considerably more stable than the unsubstituted compound.

β-Bromoethyl chlorosulfonate was made in a similar manner. It distilled at 100–105°/18 mm. Both esters were reported to be effective as lachrymators. The bromo compound has also been made[215] from the sulfite and sulfuryl chloride.

$$(BrCH_2CH_2)_2SO_3 + SO_2Cl_2 \rightarrow BrCH_2CH_2OSO_2Cl + BrCH_2CH_2Cl$$

Trifluoroethyl alcohol reacts with sulfuric acid with considerable difficulty.[254] The barium salt, $(CF_3CH_2OSO_3)_2Ba \cdot H_2O$, was isolated.

The magnesium salt of tribromoethyl hydrogen sulfate,[255] prepared by esterification of the alcohol, has been found to be of no value as a rectal anesthetic.

3-Chloropropyl chlorosulfonate and 2,3-dichloropropyl chlorosulfonate have also been reported.[256] They are more stable than the corresponding unsubstituted propyl compound. The monochloro derivative has also been converted into the sulfate.

$$ClCH_2CH_2CH_2OSO_2Cl + (ClCH_2CH_2CH_2)_2SO_3 \rightarrow$$
$$(ClCH_2CH_2CH_2)_2SO_4 + ClCH_2CH_2CH_2Cl + SO_2$$

Concentrated sulfuric acid reacts with 1,2-dichloroethylene[71b] to give a compound which hydrolyzes to chloroacetaldehyde and hence must have the structure indicated.

$$ClCH{=}CHCl + H_2SO_4 \rightarrow ClCH_2CHClOSO_3H$$

$$ClCH_2CHClOSO_3H + H_2O \rightarrow ClCH_2CHO + HCl + H_2SO_4$$

Glycerol α,γ-dichlorohydrin reacts with chlorosulfonic acid at 0° to give a solid ester.[257]

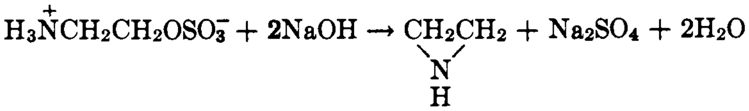
$$(ClCH_2)_2CHOH + ClSO_3H \rightarrow (ClCH_2)_2CHOSO_3H + HCl$$

β-Aminoethyl Hydrogen Sulfate. By heating β-hydroxyethylammonium hydrogen sulfate (ethanolamine hydrogen sulfate) gradually to 250° or for an hour at 130° it is converted into the ester.[258a, b] This compound has been prepared also by the action of 20% oleum at ice temperature[258c] and by other concentrations of sulfuric acid.[258d]

$$HOCH_2CH_2NH_3HSO_4 \rightarrow H_3\overset{+}{N}CH_2CH_2OSO_3^- + H_2O$$

Hydrolysis of the aminoethyl hydrogen sulfate occurs slowly in water solution at 100°. At room temperature no discernible amount of barium sulfate was obtained after ten hours' standing with aqueous barium chloride. In acid solution hydrolysis is not increased, but refluxing for several hours with 25% potassium hydroxide resulted in 75% of the sulfur appearing as sulfate ions. Titration of the ester with standard alkali using phenolphthalein as the indicator gave a somewhat indefinite end point but a "formol" titration gave good results.

When the ester is distilled with 40% sodium hydroxide solution one product of the reaction is ethyleneimine,[258a] which has been isolated in a yield of 26.5%.



$$H_3\overset{+}{N}CH_2CH_2OSO_3^- + 2NaOH \rightarrow \underset{\underset{H}{N}}{CH_2CH_2} + Na_2SO_4 + 2H_2O$$

The formation of aminoalkyl hydrogen sulfates from unsaturated amines and sulfuric acid has been mentioned earlier.[91,92] The properties of these compounds have been but little investigated.

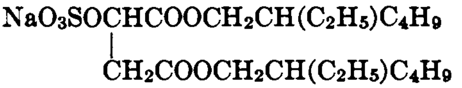
Hydrogen Sulfates of Hydroxy Acids and Their Derivatives. The neutral sodium salt of the hydrogen sulfate of 10-hydroxystearic acid has been isolated from the product obtained by the action of chlorosulfonic acid upon an ether solution of the hydroxy acid.[259] Esterification of 9,10-dibromo-12-hydroxystearic acid (from ricinoleic acid) by chlorosulfonic acid in ether[260a] and of the diiodo compound by sulfuric acid[260b] have been reported.

The hydrogen sulfates of alkyl α-hydroxyisobutyrates have been utilized in the preparation of alkyl methacrylates.[261] This is one of the rare references to sulfate esters of a tertiary hydroxyl. Higher

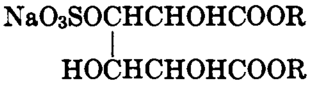
$$\mathrm{(CH_3)_2C(OH)COOR} \xrightarrow{\mathrm{ClSO_3H}} \mathrm{(CH_3)_2C(OSO_3H)COOR} \rightarrow \mathrm{CH_2{=}C(CH_3)COOR}$$

alkyl esters of hydroxy acids such as octadecyl lactate[262a] and also of branched-chain hydroxy acids[262b] may be converted into acid sulfates by sulfuric acid. Di- and polyhydroxy acids have been sulfated by spraying 5 to 10% oleum into the reaction mixture.[263a] The chlorosulfonate of ethyl lactate has been prepared from the sulfite.[263b]

The sodium salts of hydrogen sulfates derived from the esters of hydroxydicarboxylic acids are useful as wetting agents.[264] Examples of these compounds are shown by the formulas.



$$\begin{array}{l}\mathrm{NaO_3SOCHCOOCH_2CH(C_2H_5)C_4H_9}\\ \qquad\quad |\\ \qquad\quad \mathrm{CH_2COOCH_2CH(C_2H_5)C_4H_9}\end{array}$$



$$\begin{array}{l}\mathrm{NaO_3SOCHCHOHCOOR}\\ \qquad\qquad |\\ \quad\ \ \mathrm{HOCHCHOHCOOR}\end{array}$$

The action of sulfuric acid upon the hydroxynitriles obtained from aldehydes and ketones results in the formation of the hydrogen sulfates of the hydroxyamides,[265] which can be hydrolyzed readily.

$$\mathrm{R_2C(OH)CN + H_2SO_4 \rightarrow R_2C(OSO_3H)CONH_2} \xrightarrow{\mathrm{H_2O}} \mathrm{R_2C(OH)CONH_2}$$

The synthesis of the hydrogen sulfate of ricinoleic acid by various methods has been mentioned earlier. The free acid sulfate is a yellow oil.[266a] Adding sodium chloride to its aqueous solution gives the acid salt, $\mathrm{CH_3(CH_2)_6CH(OSO_3Na)CH{=}CH(CH_2)_7COOH}$. The neutral salt has been isolated from sulfonated castor oil. Hydrolysis of the sulfate group occurs more rapidly in acid than in alkaline solution.[266a, c] Physical properties of the aqueous solutions of the sodium, ammonium, and potassium salts have been investigated.[266b]

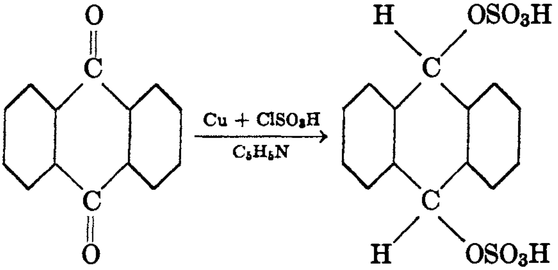
Hydrogen Sulfates of Arylcarbinols. The reaction of benzyl alcohol with sulfuric acid results in a resinous material[267] due to intermolecular dehydration, but it is possible to prepare benzyl hydrogen sulfate by the use of chlorosulfonic acid in pyridine.[267b] Methylene sulfate likewise yields the benzyl ester when treated with benzyl alcohol.[268]

$$\mathrm{C_6H_5CH_2OH + CH_2SO_4 \rightarrow C_6H_5CH_2OSO_3H\ [+\ HCHO]}$$

Triphenylcarbinol dissolves in sulfuric acid to give the acid ester as mentioned earlier. Dilution with water regenerates the carbinol.[269] Tri-*p*-tolylcarbinol has also been converted into the ester.[270]

Treating ephedrine with cold sulfuric acid forms the ester of pseudoephedrine,[271] inversion occurring. This ester exists as the dipolar ion.

When anthraquinone is heated with pyridine, chlorosulfonic acid, and copper, the diester of the corresponding alcohol is believed to be produced.[272]



The action of oxidizing agents such as lead dioxide in the presence of sulfuric acid upon the methylanthraquinones results in the formation of the acid sulfates of the ω-hydroxy compounds.[273]

Hydrogen Sulfates of Cyclic Alcohols. The technical interest in the hydrogen sulfates of cyclic alcohols has been mentioned earlier.[104] Cyclohexyl hydrogen sulfate is produced when cyclohexanol is treated with chlorosulfonic acid or oleum.[274] Borneol and menthol have been converted into the hydrogen sulfates by action of methylene sulfate.[275] Treating turpentine oil with 10% of its weight of sulfuric acid yields among other things the hydrogen sulfates of borneol and *d*-fenchyl alcohol,[276] which are stable in acid solution.

Several salts of cholesteryl hydrogen sulfate have been described. This ester may be prepared by the action of chlorosulfonic acid or sulfur trioxide upon cholesterol in the presence of pyridine in chloroform solution.[277]

HYDROGEN SULFATES OF GLYCOLS AND GLYCEROLS

Concentrated sulfuric acid reacts with ethylene chlorohydrin at 150° with evolution of hydrogen chloride[278] to give a compound identical with that obtained from ethylene glycol with the same reagent.[279]

$$HOCH_2CH_2Cl + H_2SO_4 \rightarrow HOCH_2CH_2OSO_3H + HCl$$

This ester has likewise been prepared by the action of chlorosulfonic acid upon the glycol.[280] The barium salt is highly soluble in water.

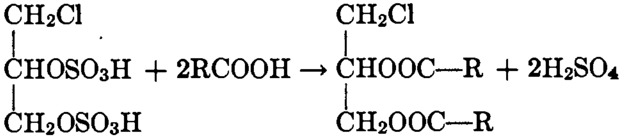
Heating its water solution resulted in a slow precipitation of barium sulfate. Adding two moles of chlorosulfonic acid to one of the glycol gives the bis-(hydrogen sulfate), a thick syrup which dissolves in water with the evolution of heat and hydrolyzes slowly at ordinary temperatures. The potassium and barium salts were described.

Both hydroxyl groups of propylene glycol are esterified when it is treated with a large excess of sulfuric acid.[281] This ester can be resolved by strychnine into its optical isomers. It was found to be very stable in water solution, complete hydrolysis not occurring even after

$$CH_3CHOHCH_2OH + 2H_2SO_4 \rightarrow CH_3CH(OSO_3H)CH_2OSO_3H + 2H_2O$$

boiling with strong acid. Several salts were characterized.

The bis-(hydrogen sulfate) has been made from 1,10-octadecandiol by treatment with chlorosulfonic acid in ether solution.[260] The neutral sodium salt was isolated in the pure state. A monoacid sulfate of unknown structure has been made from epichlorohydrin and sulfuric acid.[278] It was described as a thick oil. By treating epichlorohydrin with a mixture of nitric and sulfuric acids a mixed ester of the structure $ClCH_2CHONO_2CH_2OSO_3H$ was obtained. This was described as a water-insoluble oil, a description hardly in accord with its supposed structure.[282] Glycerol α-chlorohydrin when heated with sulfuric acid [283] gives mostly the bis-(acid sulfate) accompanied by 3 to 5% of glycerol bis-(hydrogen sulfate). This mixture of esters reacts with a fatty acid to give the corresponding esters of the fatty acid.



$$\begin{array}{l} CH_2Cl \\ | \\ CHOSO_3H \\ | \\ CH_2OSO_3H \end{array} + 2RCOOH \rightarrow \begin{array}{l} CH_2Cl \\ | \\ CHOOC{-}R \\ | \\ CH_2OOC{-}R \end{array} + 2H_2SO_4$$

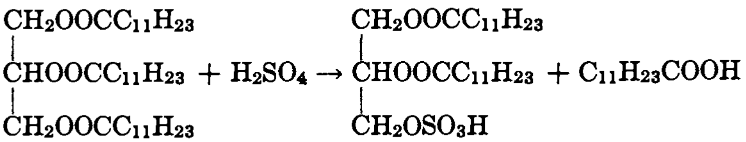
Allene dissolves in sulfuric acid to give a bis-(hydrogen sulfate),[284]

$$H_2C{=}C{=}CH_2 + 2H_2SO_4 \rightarrow CH_3C(OSO_3H)_2CH_3 \xrightarrow{2H_2O} (CH_3)_2CO + 2H_2SO_4$$

which hydrolyzes to acetone and so must have the structure indicated. Further studies of the stability of this type of ester would be of interest.

By mixing two parts of sulfuric acid with one of glycerol a mono ester results.[285] It decomposed when efforts were made to obtain it in a pure state. Its use in the treatment of hides has been suggested.[286]

A mixed glyceryl ester [287] of lauric and sulfuric acids is produced when one mole of trilaurin is treated with seven moles of concentrated sulfuric acid.



$$\begin{array}{l}CH_2OOCC_{11}H_{23}\\ |\\ CHOOCC_{11}H_{23}\\ |\\ CH_2OOCC_{11}H_{23}\end{array} + H_2SO_4 \rightarrow \begin{array}{l}CH_2OOCC_{11}H_{23}\\ |\\ CHOOCC_{11}H_{23}\\ |\\ CH_2OSO_3H\end{array} + C_{11}H_{23}COOH$$

To replace all the lauric acid residues it is necessary to employ a very large excess of 100% sulfuric acid at a low temperature.

Glycerol when mixed with four times its weight of 98% sulfuric acid is quickly converted into the α,γ-bis-(hydrogen sulfate).[288] The sulfate groups are replaced readily by treatment of the ester with an aliphatic acid.[289] The potassium and barium salts were prepared.

$$CH_2OHCHOHCH_2OH + 2H_2SO_4 \rightarrow CH_2(OSO_3H)CHOHCH_2OSO_3H + 2H_2O$$

$$CH_2(OSO_3H)CHOHCH_2OSO_3H + 2RCOOH \rightarrow (CH_2OOCR)_2CHOH + 2H_2SO_4$$

By the action of chlorosulfonic acid upon glycerol at 0° all three hydroxyl groups are esterified.[280] Claësson reported this compound readily hydrolyzed by water, but it was found later[290] that only two of the sulfate groups are easily removed, hydrolysis of the third being incomplete after boiling a water solution of the ester for 48 hours. It is unlikely that equilibrium had been attained, as a dilute solution (21.5 g. in 500 ml. of water) of the ester was used.

The sulfuric acid esters of higher aliphatic polyhydroxy alcohols such as heptadecantriol have been patented[291] as wetting-out agents.

Hydrogen Sulfates of Carbohydrates and Related Compounds

Claësson[84] was able to prepare by the action of chlorosulfonic acid on erythritol at a low temperature a mono- and a tetra-(hydrogen sulfate). Mannitol reacts with sulfuric acid[292] to give a number of compounds of uncertain structure. At 38–40° a high yield of a bis-(hydrogen sulfate) which contains a double bond and an ethylene oxide ring is obtained. Highly sulfated products are formed from mannitol, dulcitol, and dulcitan by the action of chlorosulfonic acid.

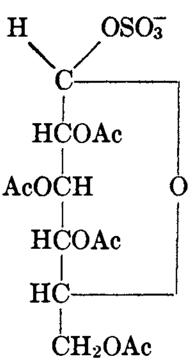
The hydrogen sulfates of glucose have received considerable attention because of their value in throwing light upon the structure of other glucose derivatives. Chlorosulfonic acid in excess converts *d*-glucose into a chloro compound with the structure $CH_2OSO_3H(CHOSO_3H)_3CHClCHO$.[280] In water at ordinary temperature the chlorine hydrolyzes, leaving the four sulfate groups intact. After a day, however, one of these is removed, and by heating the solution *d*-glucose is regenerated. The rate of hydrolysis of a mixture of *d*-glucose polysulfates permits a guess as to how much mono-, di-, and poly esters are present.[293] The chloroglucose derivative is also obtained by the action of chlorosulfonic acid upon dextrin, starch, and cellulose.[294] By addition of the cellulose reaction mixture to acetic anhydride a *d*-glucose pentacetate is obtained.

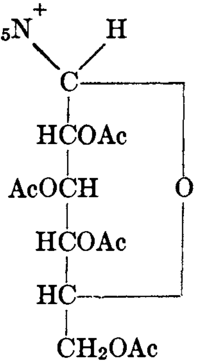
A mono-(hydrogen sulfate) of *d*-glucose results[295] when a mixture of chlorosulfonic acid and chloroform is added to a pyridine solution of the sugar. A number of the salts of this ester have been characterized and their mutarotations investigated.[296] These salts are not fermented by yeast and hence can be conveniently freed from unreacted sugar. An enzyme has been found,[297] however, that will ferment the ester.

The hydrogen sulfates of 1,2-acetoneglucose and 1,2,5,6-diacetoneglucose have been prepared[298] from the glucose derivatives by treatment with chlorosulfonic acid or sulfuryl chloride in pyridine. Neither of these compounds reduces Fehling's solution or forms an insoluble barium salt. The rates of hydrolysis of the mono- and diacetone derivatives were $K = 4 \times 10^{-2}$ and 6×10^{-2}, respectively. The diacetoneglucose hydrogen sulfate gave the monoacetoneglucose 3-(hydrogen sulfate) when hydrolyzed, while the other compound has the sulfate group in the 6-position.

By acetylation of the reaction mixture containing *d*-glucose hydrogen sulfate[299] with sodium acetate and acetic anhydride the tetraacetylglucose 6-(hydrogen sulfate) resulted. The isomeric 1-(hydrogen sulfate) is obtained by the action of chlorosulfonic acid upon tetraacetylglucose. This sulfate is easily hydrolyzed.

An addition product obtained from the action of silver sulfate upon acetobromoglucose or of silver carbonate upon a mixture of tetraacetylglucose 1-(hydrogen sulfate) and acetobromoglucose in pyridine was found[300] to contain a molecule of pyridine in the form of a quaternary ammonium compound containing two glucose molecules as shown in the formula. The formation of this compound can be explained by the addition of the neutral sulfate of tetraacetylglucose to the pyridine just as methyl sulfate would add under the same circumstances. This salt formed a neutral aqueous solution in which it was completely ionized, the apparent molecular weight being 400 while in acetic acid it was about twice this value. The reaction giving this type of product was found to be highly characteristic and limited to the acylated 1-halogen sugars of the pyranoid type. Glucose halogen derivatives of the furanoid type give syrupy products having the sulfate present





as a salt with no quaternary ammonium linkage. The significance of this behavior as related to the structure of various sugars has been discussed[301] in detail.

The sulfate group in triacetyl-β-methyl-*d*-glucoside sodium sulfate was found to be stable to alkaline hydrolysis, β-methyl-*d*-glucoside sodium sulfate being formed.

The action of potassium pyrosulfate upon sucrose in dilute potassium hydroxide solution[302] and subsequent addition of barium acetate solution resulted in a 16.5% yield of the barium salt of a sucrose hydrogen sulfate. It does not reduce Fehling's solution and has the rotation $\alpha^{29°}_{\mathrm{D}} = 26.09$, while a sulfate formed by the action of chlorosulfonic acid upon sucrose gives a barium salt[303] having the rotation $\alpha^{22°}_{\mathrm{D}} = 37.64$. The structures of these esters have not been determined. By the action of chlorosulfonic acid upon sucrose in pyridine[304] there is formed a mixture of hydrogen sulfates, containing from one to four sulfate groups, which have not been separated.

By the partial hydrolysis of agar-agar there is formed among other things the hydrogen sulfate of a polysaccharide which was found[305] to contain in combination 39.5% galactose, 8.2% pentose, about 8% of sulfate, an unidentified hexose, and a substance showing a ketose reaction. Electrodialysis of commercial agar yields an "agar acid" having a molecular weight of 3000 or more[306] which is apparently the source of the above compound.

Some attention has been given to hydrogen sulfates of the more complex carbohydrates.[307] Cotton treated with chlorosulfonic acid in the cold for 24 hours is degraded into α-chloroglucose tetra-(hydrogen sulfate),[280,294] but in the presence of pyridine at 100° dry cotton or filter paper is converted into a gelatinous mass[308] soluble in water to a colloidal solution. From this solution various salts were obtained. It was not established whether the substance was a derivative of cellulose itself or some partial degradation product. The barium salt when given a second treatment with chlorosulfonic acid gave an ester with a content of three hydrogen sulfate groups for each six-carbon unit of cellulose. The first treatment gave a product averaging 2.78 such groups, and never more than 2.9 such groups even after several weeks' standing with the chlorosulfonic acid reagent.[809] It was possible, however, to introduce the three hydrogen sulfate groups in one operation by the use of sulfur trioxide as a gas or in carbon bisulfide solution.[810] Well-characterized salts which were stable in air were isolated. Strangely enough, the mono- and diesters were not formed even by the use of an insufficient amount of sulfur trioxide, unchanged cellulose being recovered. More than three moles of sulfur trioxide may be added on to each cellulose unit of six carbon atoms, but these come off readily as sulfuric acid when the reaction product is placed in water. The potassium salt $[C_6H_7O_5(SO_3K)_3]_n$ which separates from its water solution at 0° contains 12–14% water which can be driven off by heating in a high vacuum at 100°. It is a tasteless amorphous material that dissolves readily in hot water to give a colloidal solution. It is insoluble in organic solvents and is precipitated from water solution by the addition of potassium hydroxide. Boiling its water solution leads to only slight decomposition, and even with aqueous alkali at 150° only a slow reaction occurs. Hydrochloric acid reacts slowly to give chiefly *d*-glucose, but alcoholic hydrogen chloride liberates sulfuric acid and only slightly changed cellulose. Because of the low temperature at which the ester is formed it was believed to be a true derivative of cellulose. However, a water solution of the sodium salt of the product obtained by the chlorosulfonic acid-pyridine method is more viscous and this may indicate a higher molecular weight for the latter compound.

The reaction of sulfuryl chloride with starch [811] in dilute alkali gives a mixture of products containing small quantities of sulfur, the molecular weights indicating that considerable degradation of the starch molecule has occurred. By the use of the (chlorosulfonic acid)-pyridine reagent an ester of starch is obtained [812] from which a potassium salt with the composition $C_6H_8O_5(SO_3K)_2 \cdot 2.5H_2O$ has been isolated.

B. ARYL HYDROGEN SULFATES

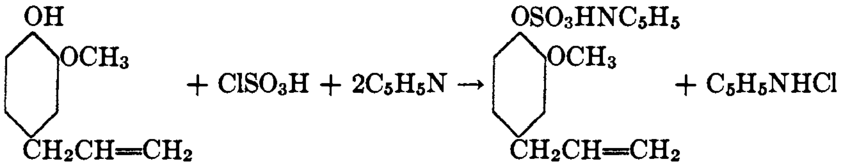
The discovery that part of the sulfuric acid present in urine could not be precipitated as barium sulfate unless the solution were boiled with hydrochloric acid [813] led to the isolation of potassium phenyl sulfate and *p*-tolyl sulfate from this source. These and other aryl esters of sulfuric acid were first[314] synthesized by heating a concentrated solution of the potassium phenoxide to 60–70°, adding finely divided potassium pyrosulfate, and shaking for several hours. The yield was 25–30%, based upon the phenol. It was later[315,316] found that the yield could be increased to 80–85% by carrying out the reaction

$$C_6H_5OK + K_2S_2O_7 \rightarrow C_6H_5OSO_3K + K_2SO_4$$

in the presence of dimethylaniline. Esters of resorcinol, catechol, hydroquinone, the three hydroxybenzoic acids, and gallic acid were prepared by this modified method.

Heating phenol with aminosulfonic acid at 100° for 24 hours produces ammonium phenyl sulfate,[317] a higher temperature leading to nuclear sulfonation. Substituted phenols behave similarly.

A method of sulfate synthesis developed in connection with a study of the conversion of eugenol to vanillin[318] consists in esterifying the phenol by the action of chlorosulfonic acid in the presence of pyridine in carbon disulfide or chloroform[315] solution. Adding potassium hydroxide to the reaction mixture gave pyridine, potassium eugenyl sulfate, and potassium chloride. Boiling the ester with 10% aqueous sodium or potassium hydroxide converted it into the isoeugenyl compound without hydrolysis. The potassium salts of the esters of phenol, thymol, α-naphthol, and benzyl alcohol were prepared in the same manner as that from eugenol. More recently[316,319] it has been found that a dialkylaniline, which is readily recovered, may be substituted for the pyridine. The phenol was added to the diethylaniline and chlorosulfonic acid in carbon disulfide at a low temperature rather than adding the chlorosulfonic acid last as the yields were much higher, 90% of the theoretical amount of sodium phenyl sulfate being obtainable. The ester of *p*-nitrophenol was made by adding a sulfur dioxide solution of sulfur trioxide to the phenol and pyridine or by the addition of the phenol to a solution of the pyridine-(sulfur trioxide) complex in benzene. Refluxing the benzene solution gave 90–94% of *p*-nitrophenyl hydrogen sulfate.



Later it was found[320a] that some aryl hydrogen sulfate is formed when a phenol is treated with chlorosulfonic acid at a low temperature even in the absence of a tertiary base. The yields are low, however, sulfonic acids being the chief products. These esters are known only as their salts, the free esters being unstable. Potassium phenyl sulfate decomposes slowly in contact with moist air, and more rapidly in hydrochloric acid solution. Refluxing with dilute acetic acid causes very slow hydrolysis, which is prevented by the addition of sodium acetate. Various enzymes induce no change[316] in 10 days at 40°. A detailed study of the hydrolysis of substituted aryl hydrogen sulfates in acid solution has been made by Burkhardt and co-workers.[320b,c] In contrast to the ease of hydrolysis in acids, boiling with concentrated potassium hydroxide causes no appreciable change. Even at 150° the reaction is slow. Heating with concentrated ammonia solution causes some hydrolysis but no aniline formation. Similarly, heating with aniline gives no diphenylamine. On the other hand, heating with sodium phenoxide gives a 25% yield of phenyl ether.[321] Here as in other

$$C_6H_5ONa + C_6H_5NaSO_4 \rightarrow (C_6H_5)_2O + Na_2SO_4$$

compounds the carbon-oxygen bond attached to the carbon of the benzene ring is difficult to break. Diazo compounds do not couple with potassium phenyl sulfate in alkaline solution. Nitrous acid has no action even after several days' standing, whereas concentrated nitric acid decomposes the ester with subsequent nitration of the phenol.

When the dry potassium phenyl sulfate is heated to 100°, decomposition begins and this goes to completion rapidly at 150–160° with formation of potassium *p*-phenolsulfonate. When the sodium salt is heated some of the *ortho* isomer appears in the reaction mixture. There is thus some similarity to the metal phenyl carbonates, in which the product also varies with the salt.

The esterification of the phenol hydroxyl with sulfuric acid stabilizes the compound against oxidizing agents. Thus potassium isoeugenyl sulfate is oxidized by ozone[318] to the vanillin derivative and the tolyl potassium sulfates are converted by the action of potassium permanganate in alkaline solution into the corresponding derivatives of the hydroxybenzoic acids. Under similar conditions the naphthyl compounds give a mixture of very soluble acids which are difficult to separate.[316] From the α-naphthyl compound a little hydroxyphthalic and phthalic acids were isolated.

The *p*-toluidine salts of the tolyl hydrogen sulfates possess sharp melting points which are characteristic.[322] It is quite probable that arylamine salts would also form suitable derivatives for other aryl hydrogen sulfates.

The esters of nitrophenols and nitronaphthols can be reduced to the azo, hydrazo, or amino compounds[323] without removing the sulfate group. With nitrous acid the *ortho* amino compounds split off potassium hydrogen sulfate, but the *meta* and *para* isomers diazotize normally, the diazonium compounds coupling to give water-soluble dyes still containing the ester group.

Aryl fluorosulfonates result from heating the diazonium salts of fluorosulfonic acid[324] above 100°. Phenyl fluorosulfonate distils at

$$ArN_2SO_3F \rightarrow ArOSO_2F + N_2$$

180°, and *p*-chlorophenyl fluorosulfonate at 211–213°. These compounds do not hydrolyze readily. The claim is made that they are useful for combating moths.

Sodium phenoxide and sulfuryl chloride react[325] in benzene solution at 0–5° to form phenyl chlorosulfonate. This compound distils at

$$C_6H_5ONa + SO_2Cl_2 \rightarrow C_6H_5OSO_2Cl + NaCl$$

98°/12 mm. and with slight decomposition at 221–222°/735 mm. Compounds of this type are stable toward acids, but alkali converts them into aryl sodium sulfates. Probably their most interesting reaction is that of arylation of sodium alkoxides and phenoxide, which occurs readily in an anhydrous solvent with formation of the corresponding ethers.

Some substituted anthrahydroquinone esters of sulfuric acid[326] made by reducing the corresponding anthraquinones with zinc dust in the presence of the (sulfur trioxide)-pyridine addition product have been patented as dye intermediates. Esters of 1,2,2′,1′-dianthraquinonazone have been prepared similarly.[327]

Hydrogen sulfate esters of aminoanthrahydroquinones may be prepared by treating the acylated compounds with pyridine sulfotrioxide in the presence of copper powder and then removing the acyl group by hydrolysis.[328]

C. ALKYL SULFATES

Methyl and ethyl sulfates are the only members of this series of compounds that have received sustained attention, and it is only comparatively recently that the ethyl ester has become readily available. The usefulness of the methyl and ethyl compounds indicates that the higher homologs are worthy of more study. It should be recognized, however, that none of these is likely to replace the corresponding alkyl bromide as an alkylating agent for general purposes, since only one of the alkyl groups of the sulfate is capable of entering into most reactions. This is a severe handicap unless the unreacted alkyl is readily recoverable in useful form. There are, however, undoubtedly particular instances where the somewhat greater reactivity of the higher alkyl sulfates will make them useful in laboratory work. Comparatively recently[329,330] it has been shown that the *n*-alkyl sulfates up to octadecyl may be made from the alcohols by the following reactions.

$$ROH + SO_2Cl_2 \rightarrow ROSO_2Cl + HCl$$

$$2ROH + SOCl_2 \rightarrow R_2SO_3 + 2HCl$$

$$ROSO_2Cl + R_2SO_3 \rightarrow R_2SO_4 + RCl + SO_2$$

In addition to the products indicated, appreciable amounts of olefins are formed. These were believed to arise from the following reaction.

$$ROSO_2Cl + R_2SO_3 \rightarrow R_2SO_4 + R'CH{=}CH_2 + SO_2 + HCl$$

If this procedure can be adapted to the preparation of considerable quantities of the alkyl sulfates they may be expected to become common laboratory materials.

A number of procedures have been described in the patent literature for the preparation of alkyl sulfates by the action of olefins with sulfuric acid.[331] Details of this reaction for ethyl sulfate are given in a subsequent section.

Although the preparation of alkyl sulfates by the action of sulfuryl chloride with alcohols has been patented,[332] the yields obtained are generally very low.

METHYL SULFATE

Methyl Sulfate (1); Preparation. Methyl sulfate was first obtained in a somewhat impure state about a century[333] ago, but the first extensive study of its preparation was made much later by Claësson.[34] It was obtained in both instances by distillation of methyl hydrogen sulfate, which pyrolyzes as follows.

$$2CH_3HSO_4 \rightarrow H_2SO_4 + (CH_3)_2SO_4$$

This is an equilibrium reaction, the approximate number of moles of each product present at 150–160° being $1H_2SO_4$, $1(CH_3)_2SO_4$ and $3CH_3HSO_4$.[334] The methyl hydrogen sulfate necessary for the preparation may be made from methanol and sulfuric or chlorosulfonic acid,[333,335] from methyl ether and sulfuric acid,[336] or in the other ways already discussed (see p. 8). Typical of good procedures is that described by Guyot and Simon.[337,338] Slow distillation under reduced pressure of a mixture of 100 parts of methanol and 400 parts of 60%

fuming sulfuric acid gives 90–95% of the theoretical amount of methyl sulfate. Some methyl ether is formed in the reaction, and this may be absorbed in acid used in another run. The use of 25% oleum reduces the yield of methyl sulfate to 60–65% of the theoretical amount.

Passing a stream of dry air and sulfur trioxide into a solution of methyl ether in methyl sulfate has been patented[339] as a method of preparation, as has the reaction of a mixture of sulfur dioxide and chlorine with methanol.[340] Methyl chloride and methyl hydrogen sulfate are by-products in this method, as they are in the reaction of sulfuryl chloride and methanol which, however, gives only a small yield[341] of methyl sulfate (see p. 8).

$$(CH_3)_2O + SO_3 \rightarrow (CH_3)_2SO_4$$

$$SO_2 + Cl_2 + 2CH_3OH \rightarrow (CH_3)_2SO_4 + 2HCl$$

Methyl sulfate is also reported to result from passing methanol over heated sodium pyrosulfate,[342] probably according to the following equation.

$$Na_2S_2O_7 + 2CH_3OH \rightarrow (CH_3)_2SO_4 + Na_2SO_4 + H_2O$$

Methyl ether reacts with either the pyrosulfate or methyl chlorosulfonate.

$$(CH_3)_2O + CH_3OSO_2Cl \rightarrow (CH_3)_2SO_4 + CH_3Cl$$
$$(CH_3)_2O + Na_2S_2O_7 \rightarrow (CH_3)_2SO_4 + Na_2SO_4$$

Several methods of preparation which can possibly be extended to higher homologs have been discovered. Methyl nitrite reacts with methyl chlorosulfonate[343] to give a 40% yield of methyl sulfate. Methyl hydrogen sulfate and methyl chloroformate[344] at 100° for 6 hours give a 100% yield of the same compound. The reaction is not so satisfactory with ethyl hydrogen sulfate, however. A reaction which is of more general application than the foregoing involves alkyl sulfites.[345] At ordinary temperature chlorine reacts as indicated,

$$CH_3ONO + CH_3OSO_2Cl \rightarrow (CH_3)_2SO_4 + NOCl$$

$$(CH_3)_2SO_3 + Cl_2 \rightarrow CH_3Cl + CH_3OSO_2Cl$$
$$(CH_3)_2SO_3 + CH_3OSO_2Cl \rightarrow (CH_3)_2SO_4 + SO_2 + CH_3Cl$$

the methyl chlorosulfonate reacting with another molecule of methyl sulfite when the temperature is raised to 120–140° to produce an 80% yield of methyl sulfate.

A small amount of methyl sulfate is formed in a reaction mixture containing methyl hydrogen sulfate and methyl chlorosulfonate,[336] but equilibrium favors the reverse reaction.

$$CH_3HSO_4 + CH_3OSO_2Cl \rightleftharpoons (CH_3)_2SO_4 + ClSO_3H$$

Thermal decomposition of the salts of methyl hydrogen sulfate[346] gives varying yields of methyl sulfate ranging from practically none for the potassium salt to nearly 100% of the theoretical for the lithium and alkali-earth salts. The strontium salt decomposes slowly even at room temperature; the others require up to 200°. It might be of interest to try this method of preparation with the higher alkyl sulfates.

$$Sr(CH_3SO_4)_2 \rightarrow (CH_3)_2SO_4 + SrSO_4$$

Methyl sulfate is a colorless mobile liquid which distils at 188.8°/760 mm. with slight decomposition. Its solubility in water at 18° is 28 g. per liter. Its solvent properties have been investigated by Walden.[347]

Methyl Sulfate (2); Reactions. The hydrolysis of methyl sulfate has been frequently investigated. The first methyl group is removed much more rapidly than the second.[348] If an appreciable concentration of methanol accumulates in the solution a secondary reaction occurs as indicated by the equation.

$$(CH_3)_2SO_4 + H_2O \rightarrow CH_3OH + CH_3HSO_4$$
$$(CH_3)_2SO_4 + CH_3OH \rightarrow (CH_3)_2O + CH_3HSO_4$$

The presence of small amounts of acid does not accelerate the rate of hydrolysis, a behavior common to the esters of strong acids.[349] Methyl sulfate is hydrolyzed by water alone about 5 times as fast as ethyl sulfate; with 0.5 N potassium hydroxide at 25° the ratio is about 45 to 1.[350] This difference is not because of the difference in the solubility of the two esters in water as the relative reaction rates in methyl and ethyl alcohols are about the same as in water.[351] Likewise with sodium ethoxide in ethyl alcohol at 25° methyl sulfate reacts 25 times as fast as ethyl sulfate, and at 0° the ratio is even higher, 58 to 1. Although methyl alcohol reacts with methyl sulfate more rapidly than ethyl alcohol, sodium methoxide in methyl alcohol reacts more slowly than does sodium ethoxide in ethyl alcohol.

Sodium and potassium hydroxides differ considerably in the way they influence the hydrolysis,[352] the potassium compound giving much less satisfactory results in the alkylation of phenols because it accelerates the hydrolysis side reaction to a much greater extent. Since sodium and potassium chlorides have about the same effect upon the rate of hydrolysis,[348] causing a slight decrease, the difference in the two bases can hardly be due to potassium-ion catalysis. The general effect of other salts is also to decrease the hydrolysis, probably by decreasing the solubility of the ester in water, since only heterogeneous systems were studied.

Methyl sulfate has been extensively employed as an alkylating agent both in industry and in the laboratory. The only difficulty in its use arises from its highly poisonous nature. This is believed[353] to be caused by the hydrolysis products methanol and methyl hydrogen sulfate. The eyes are particularly susceptible. However, because of low volatility, with a few precautions it can be handled safely.

The reaction of methyl sulfate with ammonia was first reported by Dumas and Peligot[354] and studied more adequately by Claësson and Lundvall.[355] Unless methyl sulfate is diluted with an inert solvent such as ether or benzene it reacts almost explosively with ammonia. The products depend upon which of the reactants is in excess, addition of methyl sulfate slowly to a saturated solution of ammonia in ether through which ammonia is passing apparently giving only methylamine, an excess of the ester forming tetramethylammonium methyl sulfate and ammonium methyl sulfate. Excess methyl sulfate with ethylamine gives a mixture of bases which were not separated, and diethylamine forms both possible products.

The reaction of aniline with methyl sulfate was first studied by Babo,[356] who reported methylaniline as the chief product. In ether solution a precipitate of phenylammonium methyl sulfate forms,[357] leaving methylaniline in solution. This mechanism was later[358] said to be

$$2C_6H_5NH_2 + (CH_3)_2SO_4 \rightarrow C_6H_5NH_3CH_3SO_4 + C_6H_5NHCH_3$$

incorrect, but the criticism was based upon a misinterpretation[359] of some color tests for the various amines in the reaction mixture. If an excess of methyl sulfate is used all three of the possible products are formed.

The methylation of a considerable number of aromatic amines has been investigated including *o*- and *p*-toluidine,[360a] *o*-aminobenzaldehyde,[361] mesidine,[362] and others.[363] The preparation of N-dimethyl-β-phenylethylamine by methylation of β-phenylethylamine in methanol solution in the presence of sodium methoxide[363] is of interest as this amine could not be obtained by the usual methylation methods involving either methyl iodide or methyl sulfate. β-(*p*-Nitrophenyl)ethylamine, however, could not be alkylated in this manner.

A very large number of quaternary ammonium compounds have been prepared by the action of methyl sulfate upon various tertiary bases.[356,360,364] Occasionally[365] reaction occurs where methyl iodide does not form the quaternary compound readily or at all. This is also true for the weakly basic diphenylamine[366] and diphenylmethylamine. By heating the amines and methyl sulfate together in alkaline solution only methylation occurs, but in the absence of this, sulfonation[367] of one of the rings also results. This unusual reaction has been formulated as follows.

$$(C_6H_5)_2NH + (CH_3)_2SO_4 \rightarrow [CH_3N(C_6H_5)_2 \cdot CH_3HSO_4] \rightarrow$$
$$(CH_3)_2N(C_6H_5)_2 \cdot HSO_4 \rightarrow CH_3N(C_6H_5)C_6H_4SO_3H + CH_3OH$$

In addition to the methanol, methyl ether was also formed owing no doubt to the reaction of methanol with the methyl sulfate, a reaction discussed later in this chapter.

$$CH_3OH + (CH_3)_2SO_4 \rightarrow (CH_3)_2O + CH_3HSO_4$$

The literature contains other examples of the reaction of methyl sulfate with various amines, but it is believed that the reactions already discussed are representative.

The reaction of methyl sulfate with phenol[368] proceeds slowly at 100–120° with the evolution of methyl ether and the formation of anisole and sulfonation products. Equations representing the probable reactions are as follows.

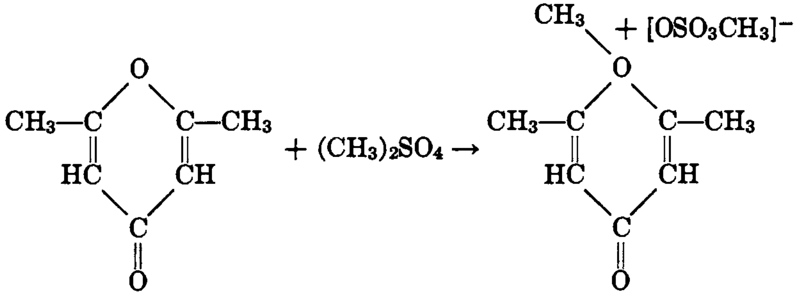
$$C_6H_5OH + (CH_3)_2SO_4 \rightarrow C_6H_5OCH_3 + CH_3HSO_4$$
$$C_6H_5OH + CH_3HSO_4 \rightarrow HOC_6H_4SO_3CH_3 + H_2O$$
$$(CH_3)_2SO_4 + H_2O \rightarrow CH_3OH + CH_3HSO_4$$
$$CH_3OH + (CH_3)_2SO_4 \rightarrow (CH_3)_2O + CH_3HSO_4$$
$$CH_3HSO_4 + C_6H_5OCH_3 \rightarrow CH_3OC_6H_4SO_3CH_3 + H_2O$$
$$CH_3OC_6H_4SO_3CH_3 + H_2O \rightarrow CH_3OC_6H_4SO_3H + CH_3OH, \text{ etc.}$$

The reaction which gives anisole also occurs in ether solution,[369] but in water or alcohol the reaction of the methyl sulfate with the solvent greatly predominates.

The methylation of phenol in aqueous alkaline solution was apparently first investigated by Ullmann.[370] It was shown by Graebe[371] that by longer heating of the reaction mixture both methyl groups could be utilized.[372] The best results in this reaction are obtained in the presence of very little water, as by adding the methyl sulfate to a mixture of molten phenol and sodium hydroxide at 45–60°, which completes the first stage of the reaction;[369, 373] heating the reaction mixture at 100–105° for an hour utilizes the second methyl group, a 95% yield of anisole being consistently obtainable.

A large number of complex phenols have been methylated successfully [374] in aqueous or alcoholic-alkaline solution. If strong alkali is harmful a sodium bicarbonate solution may be employed.[375] A thorough study has been made [376] of the methylation of phenolic compounds in xylene. It was found that phenol and its homologs are not alkylated by methyl sulfate in the presence of potassium carbonate whereas nitrophenols are more readily alkylated this way than in aqueous solution. Halogenated phenols give intermediate results. An electronic interpretation of these results was given. It would be of interest to know whether the more acidic phenols which were methylated decompose potassium carbonate under the conditions of the experiments, thus forming the more easily alkylated potassium salts. Attempts to methylate 2-hydroxy-5-nitrobenzoic acid and 2-hydroxy-3-sulfobenzoic acid by this procedure [377] gave negative results even when the reaction mixtures were heated for two months.

Thiophenol and its substitution products are very readily alkylated [378] in alkaline solution with methyl sulfate at room temperatures. The corresponding sulfonium compounds may result as by-products, but they decompose upon distillation with alkali to give the sulfides. The sulfonium compounds result in good yields from the lead salts of thiophenols and methyl sulfate.[379] Methyl sulfate adds to dimethylpyrone [380] upon warming to give an oxonium salt.



Methyl sulfate reacts with organic acids such as acetic acid,[381] methyl acetate resulting in 80–100% yields when the reaction mixture is heated to 120°. At 200° the second methyl group also reacts.

$$CH_3COOH + (CH_3)_2SO_4 \rightarrow CH_3COOCH_3 + CH_3HSO_4$$

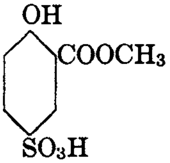
It was first noted by Dumas and Peligot [382] that potassium benzoate and formate when heated with methyl sulfate are readily converted into the methyl esters.

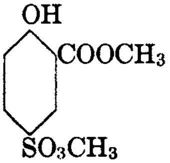
$$C_6H_5COOK + (CH_3)_2SO_4 \rightarrow C_6H_5COOCH_3 + CH_3KSO_4$$

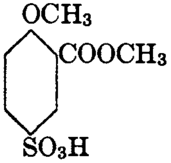
The reaction also occurs readily in aqueous solution[383] or in an organic solvent[384] even with acids not readily esterified by the usual methods. For example, the methyl esters of sulfonic acids[385] can be made by heating their sodium salts with methyl sulfate. The conversion of the salt to the ester can always be made practically complete by using an excess of methyl sulfate.

The methylation of amino acids leads to varying results.[386] Aspartic acid loses trimethylamine, leaving fumaric acid. The others for the most part form quaternary compounds, either betaines or esters of the quaternary ammonium salts. Alkylation with ethyl sulfate is much less complete than with methyl sulfate. The reactions were carried out in potassium hydroxide solution.

By the action of methyl sulfate upon dry salicylic acid a complex series of reactions occurs[387] including methylation and sulfonation. The following three products were identified.

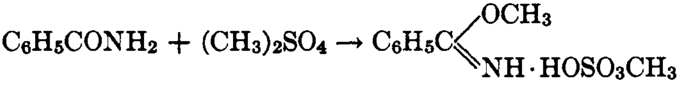






Because of rapid sulfonation only traces of methyl salicylate were present at the end of the reaction.

At a temperature of not over 100° amides and thioamides of carboxylic acids react with methyl sulfate[388a] to give good yields of the methyl hydrogen sulfate salts of imino esters.



$$C_6H_5CONH_2 + (CH_3)_2SO_4 \rightarrow C_6H_5C\begin{matrix}\diagup OCH_3 \\ \diagdown\!\!\diagdown NH\cdot HOSO_3CH_3\end{matrix}$$

It is possible that these products would be of value in preparing *ortho* esters. Methyl sulfate reacts with the sodium salt of acetanilide in benzene solution to give a 95% yield of acetmethylanilide.[388b] At 112° urea reacts vigorously[389] with methyl sulfate to form methylisourea.

$$NH_2CONH_2 + (CH_3)_2SO_4 \rightarrow NH{=}C(OCH_3)NH_2\cdot HOSO_3CH_3$$

Substituted ureas behave similarly.

It has already been mentioned (see p. 51) that methanol reacts with methyl sulfate readily. The reaction has been studied from the kinetic standpoint[390] with methyl and ethyl alcohols, the former reacting 3 to 4 times the faster at 25°. A solution of sodium hydroxide in methanol when treated with methyl sulfate[391] gives nearly the theoretical amount of methyl ether, while an alcoholic solution of potassium hydroxide is said[392] to give chiefly methanol. Heating a mixture of dry magnesium methoxide with methyl sulfate gives methyl

$$(CH_3)_2SO_4 + KOH \rightarrow CH_3KSO_4 + CH_3OH$$

ether according to the following equation.[393]

$$2(CH_3)_2SO_4 + Mg(OCH_3)_2 \rightarrow 2(CH_3)_2O + Mg(CH_3SO_4)_2$$

In a quantitative investigation of the reaction of methyl sulfate with an alkoxymagnesium bromide it was found[394] that the bromide part of the molecule reacted first.

$$2ROMgBr + (CH_3)_2SO_4 \rightarrow (RO)_2Mg + 2CH_3Br + Mg(CH_3SO_4)_2$$

It was suggested that the mechanism for this reaction involves mag-

$$2ROMgBr \rightarrow (RO)_2Mg + MgBr_2 \xrightarrow{(CH_3)_2SO_4} 2CH_3Br$$

nesium bromide. The reaction of magnesium alkoxides with methyl sulfate occurs much more slowly than the reaction with the bromide.

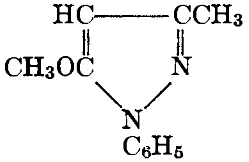
If ethylene chlorohydrin and methyl sulfate are heated together at 140–165° the ether is formed.[395] In this instance it is obviously not possible to methylate in alkaline solution.

Methyl sulfate has frequently been used in the conversion of carbohydrates into their methyl ethers. This reaction was first[396] applied to the simple sugars, then to the disaccharides,[397] and finally to the high-molecular-weight compounds such as inulin.[398] In some instances silver oxide and methyl iodide give more complete methylation than methyl sulfate, but the cheapness of methyl sulfate and its reactivity in aqueous solution make its use desirable wherever possible. In a more recently[399] developed alkylation method the potassium or sodium salt of the sugar is prepared in liquid ammonia solution, and this is treated with methyl iodide; methyl sulfate could very probably be substituted if the methylation were performed in an inert solvent, but not in liquid ammonia as the ammonia reacts with methyl sulfate vigorously.

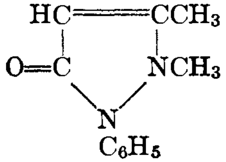
The sodium salts of ethyl acetoacetate and ethyl malonate are readily alkylated,[400] one methyl group of the methyl sulfate reacting. The resulting compounds can be further[401] methylated at 60–70° in meth-

$$CH_3COCHNaCOOC_2H_5 + (CH_3)_2SO_4 \rightarrow CH_3COCH(CH_3)COOC_2H_5 + CH_3NaSO_4$$

anol solution. Methylphenylpyrazolone similarly treated gives the 5-methyl ether (I) whereas in water solution with sodium hydroxide an 80% yield of the N-methyl compound, antipyrene (II), results.



I



II

Neither phosphoric acid nor sodium dihydrogen phosphate reacts with methyl sulfate in aqueous solution.[402] Equimolecular quantities of trisodium phosphate and methyl sulfate at room temperature give 78% of methyl disodium phosphate, 6% of dimethyl sodium phosphate, and about 10% of the methyl sulfate undergoes hydrolysis. With disodium phosphate under similar conditions the yields of methyl phosphates are lower, 33% of the methyl sulfate hydrolyzing. Alkylation with ethyl sulfate proceeded much more slowly than with the methyl homolog. The yield of methyl disodium phosphate is somewhat greater with methyl sulfate than with methyl iodide.

The preparations of methyl cyanide,[403] methyl thiocyanate,[404] nitromethane,[404] and methyl isocyanate[405] are conveniently carried out by reaction of methyl sulfate with the potassium salts of the respective radicals.

Sodium hydrosulfite[406] when heated for a minute at 70° with methyl sulfate forms sodium methyl thiosulfate, the production of this being explained as follows.

$$2Na_2S_2O_4 \rightarrow Na_2S_2O_3 + Na_2S_2O_5$$

$$Na_2S_2O_3 + (CH_3)_2SO_4 \rightarrow CH_3{-}S{-}SO_3Na + CH_3NaSO_4$$

Longer heating gave an oily mixture containing methyl sulfide and methyl disulfide. It had previously[407] been observed that alkyl thiosulfates are decomposed into disulfides when heated. Reduction of methyl disulfide by the sodium hydrosulfite was suggested as the source of the methyl sulfide. At a high temperature a small amount of methyl sulfone was also produced.

Heating methyl sulfate with dry sodium chloride[382,408a] gives a mixture of methyl chloride and methyl ether in the ratio indicated by the following equations.

$$(CH_3)_2SO_4 + NaCl \rightarrow CH_3Cl + CH_3NaSO_4$$

$$2CH_3NaSO_4 \rightarrow (CH_3)_2O + Na_2S_2O_7$$

The methyl chloride is evolved mostly below 200° and the ether above this temperature. Dry aluminum chloride reacts at room temperature.[408b] Methyl sulfate reacts with a saturated aqueous solution[409] of sodium chloride at 60–65° to give a high yield of methyl chloride. A solution of sodium bromide slightly acidified with sulfuric acid reacts readily at 30–35° to give methyl bromide in 90% yields. With concentrated hydrochloric acid, methyl chloride is evolved at 50°, and hydrobromic acid behaves similarly. These reactions are of possible value in the laboratory preparation of small quantities of the methyl halides. Magnesium bromide and iodide react readily with methyl sulfate in boiling ether solution.[328]

$$MgX_2 + 2(CH_3)_2SO_4 \rightarrow 2CH_3X + Mg(CH_3SO_4)_2$$

The reaction between stannic chloride and methyl sulfate has been recommended[410] as a convenient method for preparing stannic sulfate. The reaction occurs in two stages, the second requiring a temperature of 200°.

$$2(CH_3)_2SO_4 + SnCl_4 \rightarrow 2CH_3Cl + SnCl_2(CH_3SO_4)_2$$

$$SnCl_2(CH_3SO_4)_2 \rightarrow Sn(SO_4)_2 + 2CH_3Cl$$

When methyl sulfate is heated in contact with potassium sulfate[411] at 200° rapid decomposition ensues with evolution of methyl ether. Sodium and lithium sulfates are much less effective in causing this reaction, and barium sulfate is inert.

$$(CH_3)_2SO_4 + K_2SO_4 \rightarrow (CH_3)_2O + K_2S_2O_7$$

Although barium and calcium hydroxides[326] readily react with methyl sulfate the corresponding oxides are inert.

$$Ca(OH)_2 + 2(CH_3)_2SO_4 \rightarrow Ca(CH_3SO_4)_2 + 2CH_3OH$$

The oxides and carbonates of the heavy metals react as shown below.

$$(CH_3)_2SO_4 + Cu_2O \rightarrow Cu_2SO_4 + (CH_3)_2O$$

$$PbCO_3 + (CH_3)_2SO_4 \rightarrow PbSO_4 + CO_2 + (CH_3)_2O$$

Heating a mixture of methyl sulfate and dry potassium ferrocyanide[412] gives a complex mixture of products from which tetramethyl ferrocyanide was obtained.

An aqueous solution of potassium sulfite reacts rapidly at 80–90° with methyl sulfate[413] with formation of potassium methanesulfonate in 21–27% yields. The reaction product was isolated as the sulfonyl chloride.

$$(CH_3)_2SO_4 + K_2SO_3 \rightarrow CH_3SO_3K + CH_3KSO_4$$

Acetyl chloride reacts with methyl sulfate in the presence of zinc chloride[414] at 140–160° to give a 20–25% yield of methyl acetoxymethanesulfonate.

$$CH_3COCl + (CH_3)_2SO_4 \rightarrow CH_3COOCH_2SO_3CH_3 + HCl$$

Chlorosulfonic acid and methyl sulfate react to form a 70% yield of methyl chlorosulfonate.[415]

$$(CH_3)_2SO_4 + ClSO_3H \rightarrow CH_3OSO_2Cl + CH_3HSO_4$$

This change proceeds very slowly at room temperature, a 25% yield of methyl chlorosulfonate forming in 108 hours.

As might be expected from its behavior in other alkylations the reactivity of methyl sulfate toward Grignard reagents is greater than that of the methyl halides. In general, one mole of the Grignard reagent requires two moles of methyl sulfate for complete reaction. This can best be explained by assuming the magnesium complex to consist of the following equilibrium mixture.[416]

$$2RMgX \rightleftharpoons R_2Mg \cdot MgX_2 \rightleftharpoons R_2Mg + MgX_2$$

All these components may take part in the reaction as indicated below; the net result is the formation of the hydrocarbon and the methyl halide.

$$RMgX + (CH_3)_2SO_4 \rightarrow RCH_3 + CH_3OSO_3MgX$$

$$R_2Mg + 2(CH_3)_2SO_4 \rightarrow 2RCH_3 + (CH_3SO_4)_2Mg$$

$$RMgX + (CH_3)_2SO_4 \rightarrow CH_3X + CH_3MgOSO_3CH_3$$

$$2CH_3MgOSO_3CH_3 \rightarrow (CH_3)_2Mg + (CH_3SO_4)_2Mg$$

$$MgX_2 + 2(CH_3)_2SO_4 \rightarrow 2CH_3X + (CH_3SO_4)_2Mg$$

$$R_2Mg \cdot MgX_2 + 2(CH_3)_2SO_4 \rightarrow R_2Mg + 2CH_3X + (CH_3SO_4)_2Mg$$

$$R_2Mg \cdot MgX_2 + 2(CH_3)_2SO_4 \rightarrow 2RCH_3 + MgX_2 + (CH_3SO_4)_2Mg$$

When only one mole of methyl sulfate is added per mole of Grignard reagent, the relative amounts of hydrocarbon and methyl halide formed depend upon the nature of the Grignard complex. Thus, phenylmagnesium bromide gives a 31% yield of toluene,[417] and *p*-tolylmagnesium bromide a 74% yield of *p*-xylene. The yield of toluene becomes much higher when two moles of methyl sulfate are used.[418, 419] Likewise, the Grignard reagent from bromomesitylene[420] with over two moles of methyl sulfate gives a high yield of 1,2,3,5-tetramethylbenzene. No results are available for the action of one mole of methyl sulfate here. The action of methyl sulfate upon the Grignard reagent from 2-bromotetralin has been utilized in making the corresponding methyl compound.[421]

The results of a recent careful quantitative study of the reaction [422] of methyl sulfate with various aryl Grignard reagents are summarized in Table VII. Here one mole of methyl sulfate was used per mole of basic magnesium in the Grignard solution. The amount of halogen present was slightly (10%) higher than the basic magnesium.

TABLE VII

METHYL SULFATE AND GRIGNARD REAGENTS

Mg Compound	CH_3X %	Ar_2Mg %	ArMgX %	RMgOS-O_2OCH_3 %	CH_3OS-O_2MgX %	Mg-$(CH_3SO_4)_2$ %
C_6H_5MgBr	60.1	20.9	37.3	4.7	5.9	88.8
2,4-$(CH_3)_2C_6H_3MgBr$	50.2	0	38.4	9.3	14.2	74.8
2,4,6-$(CH_3)_3C_6H_2MgBr$	53.0	0	32.2	18.8	22.6	58.5
C_6H_5MgI	85.2	45	11.3	21.9	2.0	72.0
2,4-$(CH_3)_2C_6H_3MgI$	91.0	26.8	14.6	30.0	2.7	79.6

The information concerning the action of methyl sulfate with non-aromatic Grignard reagents is incomplete and somewhat contradictory. Houben [423] reports the absence of methyl iodide in the reaction mixture obtained from methylmagnesium iodide and believed that ethane was formed.

$$(CH_3)_2SO_4 + CH_3MgI \rightarrow CH_3OSO_3MgI + C_2H_6$$

A 75% yield of tetramethylmethane (neopentane) has been reported [424] to result from the action of *t*-butylmagnesium iodide and methyl sulfate, but a recent attempt to duplicate this reaction gave no more than a trace of the hydrocarbon.[425] The preparation of isohexane from isoamylmagnesium bromide has been mentioned,[426] but no details were supplied. From benzylmagnesium chloride and methyl sulfate a 21% yield of ethylbenzene results, on the basis of the benzyl chloride consumed. Undoubtedly this could be improved by more modern technique.

The Grignard reagent of an alkylacetylene can be alkylated by methyl sulfate.[427a]

$$RC{\equiv}CMgX + 2(CH_3)_2SO_4 \rightarrow RC{\equiv}CCH_3 + CH_3X + Mg(CH_3SO_4)_2$$

It may be expected that the metalloörganic compounds of all the more active metals will react with methyl sulfate. It has been shown that the 4,6-disodium derivative of dibenzofuran [427b] gives the methyldibenzofuran.

Benzene reacts with methyl sulfate in the presence of aluminum chloride to give as much as 60% of the theory of toluene.[428a] Biphenyl reacts similarly.[428b] An experiment in which the benzene was absent indicated that methyl chloride was not an intermediate in the reaction.

$$3(CH_3)_2SO_4 + 6C_6H_6 + AlCl_3 \rightarrow 6C_6H_5CH_3 + 6HCl + Al_2(SO_4)_3$$

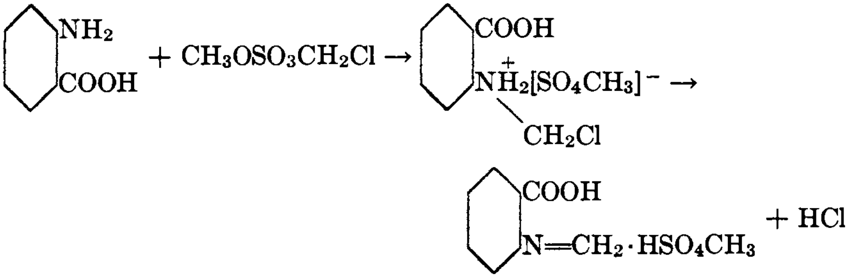
Heating 1,1-diphenylethylene with methyl sulfate results in the formation of polymers.[427c]

Halogen Derivatives of Methyl Sulfate. Two halogen derivatives of methyl sulfate are known. Sulfur trioxide reacts with chloromethyl methyl ether [429] at a low temperature to give a mixture of products from which was separated a 27% yield of the ester. The same compound results from the photochemical chlorination of methyl sulfate.[480] Hydrolysis with water occurs slowly at ordinary temperature; formaldehyde is one of the products.

$$CH_2ClOCH_3 + SO_3 \rightarrow CH_2Cl(CH_3)SO_4$$

$$CH_2Cl(CH_3)SO_4 + H_2O \rightarrow HCHO + HCl + CH_3HSO_4$$

The reaction of chloromethyl methyl sulfate with amino compounds [431] is of considerable interest. In general the products are similar to those obtained by the action of formaldehyde upon the same compounds; anthranilic acid forms a methylene derivative.



Secondary amines behave as follows.

$$RNHCH_3 + ClCH_2OSO_3CH_3 \rightarrow [RN(CH_3)]_2CH_2 \cdot HCl \cdot CH_3HSO_4$$

Ammonia reacts to form hexamethylenetetramine.[432] Cellulose in alkaline solution gives a mixture of methylenated methyl ethers of cellulose.[480b]

Chloromethyl sulfate has been obtained[438] by treating formaldehyde with chlorosulfonic acid at a temperature below 70°; the yield is 100 g. from 100 g. of paraformaldehyde.

$$2HCHO + 2ClSO_3H \rightarrow (ClCH_2)_2SO_4 + H_2SO_4$$

Chloromethyl ether reacts at 60–75° with chlorosulfonic acid to give a little of the same compound mixed with chloromethyl chlorosulfonate. Attempts to obtain chloromethyl sulfate from the ether and

$$(ClCH_2)_2O + ClSO_3H \rightarrow (ClCH_2)_2SO_4 + HCl$$

sulfur trioxide were at first unsuccessful,[432] but more recently[434] a 31% yield of product was obtained by heating the reactants in an autoclave at 180° for 50 minutes. The properties reported were b.p. 103–105/12–13 mm., and d^{12} 1.634, n_D^{12} 1.4530. Previously it had been described as an oily liquid which distils at 96–97°/14 mm. and has the density 1.60. It is a sweet-tasting, odorless, non-toxic compound, with strong bactericidal properties. However, because of the strong acids formed by hydrolysis, it can hardly be considered valuable from this standpoint.

Upon distillation with chlorosulfonic acid, it is converted into chloromethyl chlorosulfonate or methylene sulfate, depending upon the ratio of chlorosulfonic acid to ester.

$$(ClCH_2)_2SO_4 + 2ClSO_3H \rightarrow 2ClCH_2OSO_2Cl + H_2SO_4(?)$$

$$ClCH_2OSO_2Cl + ClSO_3H \rightarrow CH_2SO_4 + (?)$$

Chloromethyl sulfate reacts with cellulose[430b] in the presence of aqueous alkali to give a definite cellulose methylene ether of the composition $C_6H_7O_2(OH)(O_2CH_2)$.

ETHYL, PROPYL, AND BUTYL SULFATES

Preparation of Ethyl Sulfate. Ethyl sulfate has been prepared in many ways, most of which are of only minor importance as a source of this reagent. Small yields are obtained from the action of fuming sulfuric acid or sulfur trioxide upon ether or ethyl alcohol,[435] from sulfuryl chloride or ethyl chlorosulfonate and ethyl alcohol or sodium ethoxide,[436] and by the distillation of ethyl hydrogen sulfate slowly in a vacuum.[437] The yield is somewhat better if the ethyl hydrogen sulfate is distilled over anhydrous sodium sulfate.[438] Heating ethyl alcohol with sodium pyrosulfate[439] followed by vacuum distillation also yields some ethyl sulfate. Ethyl iodide and silver sulfate at 150°

$$Na_2S_2O_7 + C_2H_5OH \rightarrow C_2H_5HSO_4 + Na_2SO_4$$
$$2C_2H_5HSO_4 \rightarrow (C_2H_5)_2SO_4 + H_2SO_4$$
$$H_2SO_4 + Na_2SO_4 \rightarrow 2NaHSO_4$$

give a fair yield of the ester. Distillation of a mixture of barium ethyl sulfate and ammonium sulfate[440] in an attempt to prepare ethylamine gave ethyl sulfate as the chief product. This result indicates that the decomposition of barium ethyl sulfate would occur smoothly, but this

$$Ba(C_2H_5SO_4)_2 \rightarrow BaSO_4 + (C_2H_5)_2SO_4$$

has apparently not been investigated. Possibly the strontium salt would decompose even more readily, like the methyl ester.

The reaction which has made ethyl sulfate the cheapest of the alkyl sulfates is the addition of ethylene to sulfuric acid. The various factors which influence this reaction have been carefully investigated[441] and most of them have already been considered in connection with ethyl hydrogen sulfate. The ethyl sulfate may be removed from the reaction zone by entrainment with excess ethylene[442] at 100°, the ethyl sulfate condensed, and the ethylene returned to the reaction mixture. It is also possible to carry the reversible absorption of the

$$C_2H_4 + C_2H_5HSO_4 \rightleftharpoons (C_2H_5)_2SO_4$$

ethylene to completion by the use of moderate pressure (several atmospheres),[443] and this is probably the simplest way of obtaining the ester at present. By the use of high pressures, coke-oven gases containing only a few per cent of ethylene can be used satisfactorily. The sulfuric acid may contain carbonaceous impurities,[444] separation of the ester resulting by adding water and a volatile oxygen-containing solvent.

It is claimed that ethyl sulfate may be made in good yields by the action of fuming sulfuric acid or sulfur trioxide upon ethyl alcohol[445] in the presence of a dehydrating agent such as phosphorus pentoxide, but this requires verification as under these conditions the ethyl group is ordinarily further sulfonated to ethionic acid.

A number of interesting reactions in which ethyl sulfate is one of the products have been discovered by Levaillant.[446] Ethyl chlorosulfonate and ethyl carbonate react at 110° in the presence of zinc chloride to give a 75% yield of ethyl sulfate. The corresponding reaction between sulfuryl chloride and the carbonate does not give an appreciable yield of the alkyl sulfate.[447] Ethyl chlorosulfonate reacts with

$$C_2H_5OSO_2Cl + (C_2H_5)_2CO_3 \rightarrow (C_2H_5)_2SO_4 + C_2H_5Cl + CO_2$$

ethyl sulfite at 130–140° to produce ethyl sulfate. The ethyl chlorosulfonate may be prepared in the reaction mixture by addition of sulfuryl chloride to the sulfite.[446b]

$$(C_2H_5)_2SO_3 + SO_2Cl_2 \rightarrow C_2H_5OSO_2Cl + C_2H_5Cl + SO_2$$

$$(C_2H_5)_2SO_3 + C_2H_5OSO_2Cl \rightarrow (C_2H_5)_2SO_4 + C_2H_5Cl + SO_2$$

Ethyl chlorosulfonate also reacts with ethyl orthoformate with the formation of ethyl sulfate.[448]

$$C_2H_5OSO_2Cl + (C_2H_5O)_3CH \rightarrow (C_2H_5)_2SO_4 + C_2H_5Cl + HCOOC_2H_5$$

Ethyl chloroformate reacts with either methyl or ethyl hydrogen sulfate to give a 40% yield of ethyl sulfate.

$$C_2H_5HSO_4 + ClCOOC_2H_5 \rightarrow (C_2H_5)_2SO_4 + HCl + CO_2$$

Properties of Ethyl Sulfate. In contrast to the methyl ester, ethyl sulfate is described [449] as non-toxic and non-corrosive. It is also practically non-flammable. One of the ethyl groups is readily hydrolyzed

$$(C_2H_5)_2SO_4 + H_2O \rightarrow C_2H_5OH + C_2H_5HSO_4$$

by warm water. In excess ethyl alcohol at 57° the analogous reaction resulting in ether formation occurs readily.[450] The first ethyl group at this temperature reacts some 10,000 times as fast as the ethyl group in ethyl hydrogen sulfate. This latter reaction is presumably the one

$$(C_2H_5)_2SO_4 + C_2H_5OH \rightarrow (C_2H_5)_2O + C_2H_5HSO_4$$

$$C_2H_5HSO_4 + C_2H_5OH \rightarrow (C_2H_5)_2O + H_2SO_4$$

which occurs in the conversion of ethyl alcohol into ether by sulfuric acid at a much higher temperature. A detailed kinetic study of the reaction of ethyl sulfate with methyl, ethyl, and *n*-propyl alcohols was also described by Kremann [450] the rates following closely the monomolecular reaction equation when the alcohol was used in large excess. The reaction with methyl alcohol is somewhat more rapid than with the higher homologs.

In general in ethylation reactions one ethyl group reacts rapidly [880] at 50–55° (about 30° for methyl sulfate) but in order to utilize the other a temperature of 145° is necessary. This generalization is subject to exception, however, as may be noted by referring to ethyl hydrogen sulfate.

Ethyl sulfate reacts rapidly with alcoholic potassium hydroxide at 70–80°, with formation of a 50% yield of ethyl ether.[486] Presumably the remainder of the ethyl sulfate was hydrolyzed to ethyl alcohol as practically the theoretical amount of ethyl potassium sulfate was obtained.

Alkali halides react with ethyl sulfate to form the corresponding ethyl halides.[440] Hydrogen chloride reacts at 140° to give ethyl chloride.[451] Sodium sulfide and sodium hydrogen sulfide give ethyl sulfide and ethanethiol respectively. Ethylaniline, diethylaniline, ethylamine, and diethylamine are also readily obtainable, one of the alkyl groups of the ethyl sulfate reacting in each case with the amine or ammonia.

The preparation of nitroethane and of ethyl cyanide have been described by Walden,[404] reaction between the ethyl sulfate and potassium nitrite or cyanide occurring readily in aqueous solution. Ethyl isocyanate may be obtained in 95% yields by [405] heating ethyl sulfate with the dry potassium salt.

With a variety of aryl Grignard reagents ethyl sulfate gives fair yields of the hydrocarbon,[452] whereas with aliphatic magnesium compounds only alkyl halides result in appreciable yields except from acetylene magnesium derivatives.[427]

$$RMgX+(C_2H_5)_2SO_4 \rightarrow RMgOSO_3C_2H_5+C_2H_5X$$

$$2RMgOSO_3C_2H_5 \rightarrow (R)_2Mg+Mg(C_2H_5SO_4)_2$$

$$RMgX+(C_2H_5)_2SO_4 \rightarrow RC_2H_5+C_2H_5OSO_3MgX$$

$$RC{\equiv}CMgX+2(C_2H_5)_2SO_4 \rightarrow RC{\equiv}CC_2H_5+C_2H_5X+Mg(CH_3SO_4)_2$$

Ethyl sulfate reacts with hydrogen peroxide in the presence of some potassium hydroxide (potassium peroxide no doubt formed) to give a satisfactory yield of ethyl peroxide.[453]

In the ethylation of amino acids [386] only glycine could be converted into a betaine-like derivative. The reactions were carried out in aqueous alkali with slight warming of the reaction mixture.

Ethyl sulfate decomposes slowly at its boiling point, 208°/760 mm. When heated to 300° with sodium sulfate, ethylene and sodium hydrogen sulfate are the chief products.[454]

A mixed salt of a sulfinic acid obtained by the reduction of benzenesulfonyl chloride by magnesium in ether does not react with ethyl sulfate.[455] This may be because of the insolubility of the magnesium benzenesulfinate chloride in the ether, and it is likely that the reaction would proceed readily in aqueous solution.

Ethyl sulfate reacts readily with benzene in the presence of aluminum chloride to give ethylbenzene in 71% yield.[428]

β-Chloroethyl Sulfate. The only well-characterized halogen derivative of ethyl sulfate is that derived from ethylene chlorohydrin. It has been prepared by the action of sulfuryl chloride upon the alcohol[456] and upon β-chloroethyl nitrite.[457] It is also formed in good yields by the action of β-chloroethyl chlorosulfonate upon β-chloroethyl sulfite.[446] The relative yields obtained by these methods are

$$ClCH_2CH_2OSO_2Cl + (ClCH_2CH_2)_2SO_3 \rightarrow (ClCH_2CH_2)_2SO_4 + C_2H_4Cl_2 + SO_2$$

apparently not known, but the last reaction probably gives the best results. A reaction of more promise from the commercial standpoint is that of sulfur trioxide with β-chloroethyl ether.[458] This ether dissolves sulfur trioxide readily at room temperature with little evidence of reaction, but distillation of the solution gives an 85–90% yield of the sulfate. This may be looked upon as a rearrangement which occurs as follows.

$$R_2O + SO_3 \rightarrow R_2OSO_3 \rightarrow (RO)_2SO_2$$

The action of oleum upon ethylene chloride gives a mixture of products of which one is β-chloroethyl sulfate.[459] The mechanism of this reaction is not clear. The physical properties of β-chloroethyl sulfate are listed in Table IX.

The hydrolysis of β-chloroethyl sulfate with boiling water gives chiefly ethylene chlorohydrin,[458] the hydrolysis of the chlorine being slight. With concentrated hydrochloric acid ethylene chloride results, but the dry gas does not react appreciably at any temperature up to the decomposition point of the sulfate. The reaction of the ester with *n*-butyl alcohol gives a complex mixture from which only ethylene chlorohydrin and β-chloroethyl ether were isolated.

The reaction of the chloroethyl sulfate with acetic acid is slow, but with sodium acetate in acetic acid β-chloroethyl acetate formation is practically complete in an hour at the boiling point of the solution. Dry sodium benzoate reacts slowly. The reaction with the Grignard reagent is comparable to that of ethyl sulfate. β-Phenylethyl chloride and γ-phenylpropyl chloride were obtained from phenyl- and benzylmagnesium halides.

The only reaction in which the chlorine as well as the sulfate part of the molecule became involved was that with ethyl sodiomalonate.

Here a complex mixture resulted from which no pure compound was isolated.

***n*-Propyl Sulfate.** *n*-Propyl sulfate has been prepared in many ways. It was obtained by Nef[460] from *n*-propyl iodide and silver sulfate in 63% yield and in lower yield from *n*-propyl chlorosulfonate and sodium *n*-propoxide. It results from the action of sulfuryl chloride upon sodium *n*-propoxide[461] in poor yield. Levaillant[457] has obtained it from the reaction of *n*-propyl nitrite with *n*-propyl chlorosulfonate, by the oxidation of *n*-propyl sulfite with potassium permanganate,[462] and from the action of *n*-propyl chlorosulfonate upon *n*-propyl sulfite or *n*-propyl orthoformate.[463] Recently it has been obtained also from cyclopropane and sulfuric acid.[321]

$$n\text{-}C_3H_7OSO_2Cl + n\text{-}C_3H_7ONa \rightarrow (n\text{-}C_3H_7)_2SO_4 + NaCl$$

$$SO_2Cl_2 + 2n\text{-}C_3H_7ONa \rightarrow (n\text{-}C_3H_7)_2SO_4 + 2NaCl$$

$$n\text{-}C_3H_7OSO_2Cl + (n\text{-}C_3H_7)_2SO_3 \rightarrow (n\text{-}C_3H_7)_2SO_4 + n\text{-}C_3H_7Cl + SO_2$$

$$n\text{-}C_3H_7OSO_2Cl + (n\text{-}C_3H_7O)_3CH \rightarrow (n\text{-}C_3H_7)_2SO_4 + n\text{-}C_3H_7Cl + HCOOC_3H_7$$

$$2C_3H_6 + H_2SO_4 \rightarrow (n\text{-}C_3H_7)_2SO_4$$

n-Propyl sulfate reacts violently with alcoholic potassium hydroxide to give ethyl *n*-propyl ether.[460] With sodium phenoxide a 66% yield of phenyl *n*-propyl ether has been obtained.[321, 462] Upon heating, decomposition occurs[460] at 170° with evolution of a 38% yield of propylene, some sulfur dioxide, and other products. It reacts with alkaline peroxides[461] to form an unstable *n*-propyl hydrogen peroxide that was isolated as the barium salt. Sodium acetylide[321] gives *n*-propylacetylene.

γ-Chloro-*n*-propyl sulfate has been prepared by the action of γ-chloropropyl chlorosulfonate upon the sulfite.[464] The chemical properties of this ester have not been investigated.

Isopropyl Sulfate. Isopropyl sulfate is easily obtained by the action of propylene upon 98% sulfuric acid at a low temperature,[321, 465] absorption taking place much more rapidly than with ethylene. It has also been made from the reaction of sulfuryl chloride with isopropyl alcohol[462] or sodium isopropoxide[436b, 461, 466] in 25 to 30% yields. The use of the alcohol seems preferable as the yield is at least as good as with the sodium compound. However with cheap propylene available the first reaction mentioned becomes the most practical source of the ester. It may be added that Nef [460] was unable to prepare isopropyl sulfate by the action of isopropyl iodide upon silver sulfate.

The instability of isopropyl sulfate first [436b, 466] reported was because of the presence of a trace of acid.[461, 462] When free of this it can be distilled.

Hydrolysis of isopropyl and other *sec*-alkyl sulfates is facilitated by the addition of methanol to give a homogeneous mixture.[465c] Alcoholysis with isopropyl alcohol occurs readily.[465f] By treating sodium phenoxide with isopropyl sulfate a 47% yield of the ether has been obtained.[321, 462] By reaction with alkaline hydrogen peroxide solution a 50% yield of isopropyl hydrogen peroxide was obtained.[461] With *p*-tolylmagnesium bromide [466] only a 10% yield of *p*-cymene resulted. The reaction with benzene in the presence of aluminum chloride gives isopropylbenzene.[428] The reaction with sodium acetylide in liquid ammonia gives isopropylacetylene.[321]

Butyl Sulfates. *n*-Butyl sulfate has been prepared by Levaillant [393] by the action of *n*-butyl chlorosulfonate upon *n*-butyl orthoformate in 55% yields and from *n*-butyl sulfite in 70% yields. It has also recently been obtained in 90% yields from sulfuryl chloride and *n*-butyl sulfite [467] and in 55% yield by oxidation of *n*-butyl sulfite with potassium permanganate [458] in glacial acetic acid solution.

Because of its insolubility in water, alkylating reactions such as the formation of *n*-butyl cyanide, *n*-butyl phenyl ether, and *n*-butylaniline are better carried out in a mixture of water and alcohol than in aqueous solution.[467]

The reaction of *n*-butyl sulfate with some typical Grignard reagents has been studied in some detail. With an equimolecular quantity of *n*-butylmagnesium bromide reaction occurs only with the magnesium bromide linkage of the Grignard reagent. This may be formulated in two ways, both of which are probably correct if the theory [468] of the

$$\text{I. } (n\text{-C}_4\text{H}_9)_2\text{SO}_4 + n\text{-C}_4\text{H}_9\text{MgBr} \rightarrow n\text{-C}_4\text{H}_9\text{Br} + n\text{-C}_4\text{H}_9\text{MgOSO}_3\text{C}_4\text{H}_9\text{-}n$$

$$2n\text{-C}_4\text{H}_9\text{MgOSO}_3\text{C}_4\text{H}_9\text{-}n \rightarrow (n\text{-C}_4\text{H}_9)_2\text{Mg} + (n\text{-C}_4\text{H}_9\text{SO}_4)_2\text{Mg}$$

$$\text{II. } 2(\text{C}_4\text{H}_9)_2\text{SO}_4 + \text{MgBr}_2 \rightarrow 2n\text{-C}_4\text{H}_9\text{Br} + (n\text{-C}_4\text{H}_9\text{SO}_4)_2\text{Mg}$$

constitution of the Grignard reagent is accurate. Either formulation postulates that the Grignard reagent content of the reaction mixture as determined by titration should be unchanged, which is in accord with the facts. With phenylmagnesium bromide an appreciable amount of *n*-butylbenzene is also formed. This again may be explained in two ways. Although the salts formed differ in composi-

$$(n\text{-}C_4H_9)_2SO_4 + C_6H_5MgBr \rightarrow C_6H_5C_4H_9\text{-}n + n\text{-}C_4H_9OSO_3MgBr$$
$$2(n\text{-}C_4H_9)_2SO_4 + (C_6H_5)_2Mg \rightarrow 2C_6H_5C_4H_9\text{-}n + Mg(n\text{-}C_4H_9SO_4)_2$$

tion, distinguishing between the two mechanisms is difficult because of a third possibility.

$$n\text{-}C_4H_9OSO_3MgBr + (n\text{-}C_4H_9)_2SO_4 \rightarrow n\text{-}C_4H_9Br + Mg(n\text{-}C_4H_9SO_4)_2$$

As might be expected from the foregoing it is possible to convert *n*-butyl sulfate into di-*n*-butylmagnesium by the use of a small amount of magnesium halide as a catalyst. This is conveniently carried out by the addition of a trace of iodine to the magnesium turnings and ether before the ester is added.[467] Because of the relative inertness of the di-*n*-butylmagnesium toward *n*-butyl sulfate, 75–80% of the former may be obtained.

$$Mg + I_2 \rightarrow MgI_2$$
$$MgI_2 + 2(n\text{-}C_4H_9)_2SO_4 \rightarrow 2n\text{-}C_4H_9I + Mg(C_4H_9SO_4)_2$$
$$2n\text{-}C_4H_9I + Mg \rightarrow 2n\text{-}C_4H_9MgI \rightarrow (n\text{-}C_4H_9)_2Mg + MgI_2$$

The action of *n*-butyl sulfate upon benzene in the presence of aluminum chloride gives about 45% of a mixture of isomeric butylbenzenes.[428] The reaction is then analogous to that with a *n*-butyl halide.

Isobutyl sulfate was prepared in low yield by Nef[436b,460] by the action of sulfuryl chloride upon sodium isobutoxide in ligroin solution. It was not obtained by the isobutyl iodide-silver sulfate reaction.

Directions have been given in the patent literature for obtaining "dibutyl sulfate" from the action of sulfuric acid on olefins[469] preferably in the liquid phase under pressure.[470] The compound so obtained is undoubtedly the *sec*-butyl sulfate. The *tert*-butyl ester would be unstable, and it has not been possible so far to add sulfuric acid to olefins other than according to Markownikoff's rule.

HIGHER ALKYL SULFATES

In addition to the homologous series of alkyl sulfates already described (see p. 49) a few miscellaneous higher-molecular-weight esters have been made. Isoamyl sulfate has been obtained in about 15% yield by the reaction of isoamyl iodide and silver sulfate in ether solution at 130–150° under pressure;[460] some carbonizing also occurred, and sulfur dioxide was evolved. Upon warming to 80° with alcoholic potassium hydroxide the ester reacts to give ethyl isoamyl ether. By heating alone to 190° it undergoes decomposition to a 40% yield of trimethylethylene and other products. It is possible that Chapman prepared some isoamyl sulfate from isoamyl nitrite and sulfur dioxide.[471]

It has been claimed [472] that a decyl sulfate is produced by the action of the unsaturated hydrocarbon in coal tar boiling at 150–160° upon concentrated sulfuric acid. With aniline this yields an olefin. When

$$(C_{10}H_{21})_2SO_4 + C_6H_5NH_2 \rightarrow C_{10}H_{20} + C_6H_5NH_3OSO_3C_{10}H_{21}$$

refluxed with aniline another mole of decylene and aniline sulfate resulted; no evidence for alkylation was found.

Mixed Alkyl Sulfates

Several mixed alkyl esters of sulfuric acid are known. A small yield of methyl ethyl sulfate [473] is produced by the action of ethyl chlorosulfonate upon methanol, and a 50% yield by the reaction between

$$C_2H_5OSO_2Cl + CH_3OH \rightarrow C_2H_5OSO_2OCH_3 + HCl$$

ethyl hydrogen sulfate and methyl chloroformate.

$$C_2H_5HSO_4 + ClCOOCH_3 \rightarrow C_2H_5OSO_2OCH_3 + HCl + CO_2$$

Bert [474] prepared a number of mixed esters by the action of ethyl chlorosulfonate upon suspensions of sodium alkoxides in ether at −10°. The physical properties are given in Table VIII. Methyl ethyl sulfate was prepared by the same method by Thayer,[475] who, however, refluxed the ether solution, and reported a 20% yield of product distilling at 198–200°/742 mm. It has been claimed [476] that mixed alkyl sulfates result when an alkyl hydrogen sulfate prepared from an olefin and 75% sulfuric acid is treated with ethyl alcohol. This claim is remarkable inasmuch as it is well known that sulfuric acid is not completely esterified under any conditions when treated with excess alcohol.

TABLE VIII

Compound	B.P.	$d^{°C.}$	$n_D^{°C.}$
$CH_3(C_2H_5)SO_4$	85°/15 mm.	$1.228^{16.5}$	$1.399^{16.5}$
$C_2H_5(n\text{-}C_3H_7)SO_4$	107°/18 mm.	$1.140^{16.5}$	$1.411^{16.5}$
$C_2H_5(n\text{-}C_4H_9)SO_4$	117°/20 mm.	1.112^{18}	1.415^{18}

In alkylation reactions with the mixed sulfates the smaller alkyl group reacts more rapidly. Alkylation of sodium phenoxide with methyl ethyl sulfate gave an anisole/phenetole ratio of four.[475] Addition of the three mixed alkyl sulfates listed in Table VIII to phenylmagnesium bromide gave in each case only the hydrocarbon containing the smaller alkyl group. These results are in agreement with quantitative evidence that methyl sulfate is more reactive than ethyl sulfate.

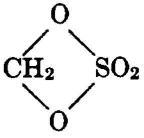
MISCELLANEOUS ESTERS OF SULFURIC ACID

By the action of allyl iodide upon silver sulfate, allyl sulfate has been obtained,[477] but it could not be purified as attempted distillation led to an explosive decomposition.

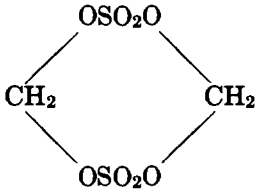
Triphenylmethyl sulfate has been prepared in similar fashion by the reaction of the chloride upon silver sulfate in liquid sulfur dioxide.[478]

Cyclic Sulfates. An interesting compound having the composition of methylene sulfate was first obtained [479] by the action of oleum upon paraformaldehyde. A modification [480] of the original method results in a 60% yield. Methylene sulfate is also one of the products obtained from chlorosulfonic acid and paraformaldehyde.[481] It likewise results from chlorosulfonic acid and chloromethyl sulfate or chloromethyl chlorosulfonate.

Methylene sulfate was originally believed to be monomolecular (I), but a more recent [482] study of its properties indicates that II better represents its behavior. For convenience it will be referred to as methylene sulfate, although the monomolecular formula is incorrect.

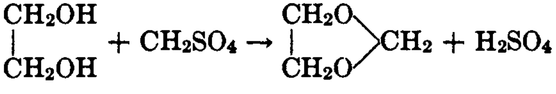


I

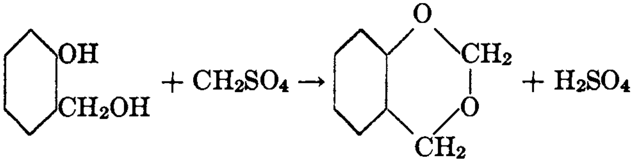


II

By heating with water or dilute alkali it hydrolyzes to sulfuric acid and formaldehyde. With alcohols and glycols formals result.[479]



The reaction with phenols has been carried out under a number of experimental procedures. It forms methylene ethers by heating with the sodium salt in acetone solution as in the case of thymol,[483] or in aqueous acetone as with guaiacol and *p*-methoxyphenol. Catechol likewise gives the methylene compound in about 25% yield in aqueous acetone.[480] With a considerable number of other phenols, heating the reactants in benzene solution in the presence of potassium carbonate gives good results. The methyleneation of *o*-hydroxybenzyl alcohol is likewise possible.

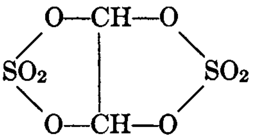


Reaction with tertiary amines such as pyridine, quinoline, and dimethylaniline forms saltlike compounds of a type analogous to betaine.

$$C_5H_5N + CH_2SO_4 \rightarrow C_5H_5\overset{+}{N}CH_2OSO_3^-$$

Reaction of methylene sulfate with alkali cellulose resulted in methylene ether formation[484] but not so much as with chloromethyl sulfate. Methylene sulfate is not particularly stable in solution in organic solvents. Heating with a variety of substances, such as ether, acetone, ethyl acetate, or benzene, brings about decomposition into carbon and sulfuric acid.[481]

A compound quite similar to methylene sulfate in its reactions is glyoxal sulfate, obtained from the action of fuming sulfuric acid upon acetylene tetrachloride in the presence of mercury or copper salts.[485] The structure of this compound is not certain, but it seems probable[482] that it is represented by I rather than II.



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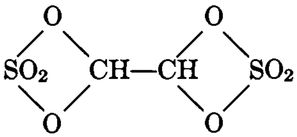

II

It is a solid which melts at 176–177°. With ethyl alcohol it forms glyoxal tetraethyl acetal, and with ethylene glycol a compound of somewhat uncertain structure which is likewise an acetal. A large number of other derivatives of glyoxal are conveniently prepared[486] by using the sulfate as the starting material.

Ethylene and trimethylene sulfates result in small yields from the action of the proper bromides upon silver sulfate in xylene solution.[482] These interesting compounds have been little investigated.

TABLE IX

Properties of Alkyl Sulfates

Compound	B.P./mm. (M.P.)	$d^{-\text{°C.}}$	$n_{\mathrm{D}}^{\text{°C.}}$
$(CH_3)_2SO_4$	69–70/10	1.333_{15}^{15}	1.3874^{20}
	189/760		
$(C_2H_5)_2SO_4$	89/9	1.172_4^{25}	1.3902^{20}
	208/760		
		1.180^{18}	1.4010^{18}
$(n\text{-}C_3H_7)_2SO_4$	95/5	1.112^{17}	1.4135^{20}
$(n\text{-}C_4H_9)_2SO_4$	97/3	1.0569_4^{25}	1.4210^{25}
$(n\text{-}C_5H_{11})_2SO_4$	117/2.5 (13)	1.0265_{25}^{25}	1.4270^{25}
$(n\text{-}C_6H_{13})_2SO_4$	125/2	1.0039_{25}^{25}	1.4344^{25}
$(n\text{-}C_7H_{15})_2SO_4$	147/1.5 (13)	0.9819_{25}^{25}	1.4362^{25}
$(n\text{-}C_8H_{17})_2SO_4$	166/2 (20)	0.9661_{25}^{25}	1.4408^{25}
$(n\text{-}C_9H_{19})_2SO_4$	(42)		
$(n\text{-}C_{10}H_{21})_2SO_4$	(37.7)		
$(n\text{-}C_{12}H_{25})_2SO_4$	(48.5)		
$(n\text{-}C_{14}H_{29})_2SO_4$	(57.9)		
$(n\text{-}C_{16}H_{33})_2SO_4$	(66.3)		
$(n\text{-}C_{18}H_{37})_2SO_4$	(70.5)		
$(i\text{-}C_3H_7)_2SO_4$	79/3.5	1.101^{17}	1.409^{17}
$(i\text{-}C_5H_{11})_2SO_4$	140–5/15		
$ClCH_2(CH_3)SO_4$	92/18	1.473^{18}	
$(ClCH_2)_2SO_4$	97/14		
$(ClCH_2CH_2)_2SO_4$	150/7	1.481^{20}	1.4620^{20}
$(ClCH_2CH_2CH_2)_2SO_4$	161/4	1.363^{20}	1.460^{25}
$(CH_2SO_4)_2$	(155)		
$C_2H_2(SO_4)_2$	(177)		
$(CH_2)_2SO_4$	(99)		
$(CH_2)_3SO_4$	(63)		

D. ARYL SULFATES

A satisfactory method for obtaining aryl sulfates has been discovered.[487] This consists in heating an aryl chlorosulfonate with a phenol in the presence of pyridine. These compounds are low-melting stable solids which can be distilled at about 1 mm. pressure. They are hydrolyzed by boiling alkali to sodium sulfate and the phenol.

$$C_6H_5SO_2Cl + C_6H_5OH + C_5H_5N \rightarrow (C_6H_5)_2SO_4 + C_5H_5NHCl$$

What is probably a mixed ester of sulfuric acid has been obtained by the action of sulfuryl chloride upon sodium *p*-hydroxybenzenesulfonate and a long-chain aliphatic alcohol.[488]

$$C_{14}H_{29}OH + SO_2Cl_2 + HOC_6H_4SO_3Na \rightarrow C_{14}H_{29}OSO_2OC_6H_4SO_3Na + 2HCl$$

REFERENCES

1. Meyer-Jacobsen, *Lehrbuch der organischen Chemie*, Second Edition, Veit and Company, Leipzig (1907), Vol. I, Part 1, p. 284.
2. Williamson, *Ann.*, **77**, 37 (1851); **81**, 73 (1852).
3. Dabit, *Crells Annalen*, **1**, 394 (1802).
4. Dumas and Peligot, *Ann.*, **19**, 293 (1836); see also Köhler, *Jahresbericht*, 579 (1856); Fridau, *Ann.*, **83**, 9 (1852); Pomeranz, *Seifensieder-Ztg.*, **59**, 293 (1932); Lindner, *ibid.*, **62**, 257 (1935); Melliand, *Textilber.*, **16**, 436 (1935).
5. Brodie, *Ann.*, **67**, 203 (1848).
6. Möslinger, *Ann.*, **185**, 62 (1877).
7. v. Cochenhausen, *Dinglers Polytech. J.*, **303**, 283 (1897).
8. Oddo and Scandola, *Gazz. chim. ital.*, 39 II, 1 (1909); *C.A.*, **5**, 879 (1911).
9. Ormandy and Craven, *J. Soc. Chem. Ind.*, **47**, 317T (1928); **48**, 293T (1929); *J. Inst. Petroleum Tech.*, **13**, 311 (1927).
10. Ipatieff and Pines, *J. Org. Chem.*, **1**, 465 (1936); see also Gutyrya, *J. Gen. Chem.* (*U.S.S.R.*), **9**, 221 (1939); *C.A.*, **33**, 6232 (1939).
11. Ormandy and Craven, *J. Inst. Petroleum Tech.*, **13**, 844 (1927).
12. Elbel, German pat., 661,883, *C.A.*, **32**, 8814 (1938); U. S. pat., 2,081,865, *C.A.*, **31**, 4988 (1937).
13. Wenzel, German pat., 640,681, *C.A.*, **31**, 5377 (1937).
14. Chemische Fabrik vorm. Sandoz, French pat., 791,590, *C.A.*, **30**, 4176 (1936).
15. Cremer, U. S. pat., 2,127,641, *C.A.*, **32**, 8042 (1938).
16. Böhme Fettchemie—Ges. m.b.H., German pat., 659,279, *C.A.*, **32**, 5853 (1938).
17. Chemische Fabrik Grünau Landshoff & Meyer A.-G., German pat., 644,686, *C.A.*, **31**, 6376 (1937).

17*a*. Henke and Lockwood, U. S. pat., 2,062,454, *C.A.*, **31**, 707 (1937).

18. McAllister, U. S. pat., 2,108,755, *C.A.*, **32**, 3056 (1938); Reibnitz, German pat., 670,297, *C.A.*, **33**, 2905 (1939).
19. Popelier, *Bull. soc. chim. Belg.*, **35**, 254 (1926).

19*a*. Schrauth, German pat., 542,048, *C.A.*, 26, 3082 (1932).

20. Suter and Oberg, *J. Am. Chem. Soc.*, **56**, 677 (1934).
21. Mauersberger, German pat., 657,705, *C.A.*, **32**, 5853 (1938).
22. Riess, *Collegium*, 580 (1931); *C.A.*, **26**, 4583 (1932).
23. Whitmore and Rothrock, *J. Am. Chem. Soc.*, **54**, 3431 (1932).
24. Swarts, *Compt. rend.* **197**, 1261 (1933).
25. Aschan and Schwalbe, *C.A.*, **27**, 701 (1933); **26**, 2729 (1932); see also Chelintzev and Kozlov, *J. Russ. Phys.-Chem. Soc.*, **46**, 708 (1914).
26. Nishizawa and Sinozaki, *J. Soc. Chem. Ind. Japan*, **32**, 779 (1929); *C.A.*, **24**, 63 (1930).

27*a*. Brandt and Ross, U. S. pat., 2,235,098, *C.A.*, **35**, 4041 (1941). *b*. Bruson and Stein, U. S. pat., 2,127,103, *C.A.*, **32**, 8042 (1938).

28*a*. Kalischer, Günther, Keller, and Hetzer, U. S. pat., 1,835,404, *C.A.*, **26,** 1146 (1932); Blumer, German pat., 557,548, *C.A.*, **27,** 619 (1933); H. T. Böhme A.-G. Chem. Fabrik, Brit. pats., 261,385 and 263,117, *C.A.*, **21,** 4084 (1927); U. S. pat., 1,801,189, *C.A.*, **25,** 3506 (1931); German pat., 553,503, *C.A.*, **26,** 5780 (1932); I. G. Farbenind. A.-G., British pat., 288,127, *C.A.*, **23,** 536 (1929); British pat., 346,945, *C.A.*, 26, 2075 (1932); British pat., 330,904, *C.A.*, 25, 226 (1931); Imperial Chemical Industries, French pat., 764,620, *C.A.*, **28,** 6010 (1934). *b*. Bunbury and Baldwin, U. S. pat., 1,981,901, *C.A.*, 29, 478 (1935); Siebenbürger, U. S. pat., 2,060,254, *C.A.*, **31,** 416 (1937); see also French pat., 41,843, *C.A.*, **27,** 4540 (1933); Baumgarten, German pat., 514,821, *C.A.*, 25, 2156 (1931).

29. Suter, U. S. pat., 2,098,114, *C.A.*, **32,** 191 (1938); Suter, Kiefer, and Evans, *J. Am. Chem. Soc.*, 60, 538 (1938).

30. Law and McNamee, U. S. pat., 2,088,027, *C.A.*, **31,** 6673 (1937); French pat., 789,405, *C.A.*, **30,** 1805 (1936); British pat., 456,214, *C.A.*, **31,** 2319 (1937).

31. Baldwin and Piggott, U. S. pat., 2,100,297, *C.A.*, **32,** 683 (1938); Hailwood, U. S. pat., 2,079,347, *C.A.*, **31,** 4420 (1937).

32*a*. Baumgarten, *Ber.*, **64B,** 1502 (1931). *b*. Walter, U. S. pat., 2,231,979, *C.A.*, **35,** 3265 (1941).

33. For examples see Bertsch, U. S. pat., 1,968,793, *C.A.*, **28,** 6010 (1934); Canadian pat., 356,113, *C.A.*, **30,** 2668 (1936); I. G. Farbenind. A.-G., British pat., 407,187, *C.A.*, **28,** 4920 (1934); British pat., 477,499, *C.A.*, **32,** 3862 (1938); German pat., 640,581, *C.A.*, **31,** 5378 (1937); Fasce and Owen, Canadian pat., 380,241, *C.A.*, **33,** 3816 (1939); Chem. Fabr. Stockhausen et Cie, British pat., 418,139, *C.A.*, **29,** 1539 (1935); Mizoguti and Onisi, Japanese pat., 130,091, *C.A.*, **35,** 1903 (1941). Frequently in patents where a "sulfating or sulfonating agent" is mentioned, the use of chlorosulfonic acid is described in one of the examples.

34*a*. Claësson, *J. prakt. Chem.*, [2] 19, 231 (1879). *b*. Orlowsky, *Ber.*, **8,** 332 (1875). *c*. Blacher, *Ber.*, **28,** 2357 (1895). *d*. Levaillant and Simon, *Compt. rend.*, 169, 140 (1919).

35. Böhme Fettchemie—Ges. m.b.H., German pat., 643,052, *C.A.*, **31,** 6254 (1937); Standard Oil Development Co., British pat., 475,075, *C.A.*, **32,** 3517 (1938).

36*a*. Engelmann, U. S. pat., 2,199,393, *C.A.*, **34,** 5857 (1940). *b*. Société anonyme des produits chimiques de fontaines, German pat., 193,830, *Chem. Zentr.*, (1908) I, 1112.

37. Kern, U. S. pat., 2,072,475, *C.A.*, **31,** 2713 (1937).

38. Schrauth, U. S. pat., 2,125,656, *C.A.*, **32,** 7613 (1938).

39. Grün and Wirth, *Ber.*, 55, 2209 (1922); see also Grün and Woldenburg, *J. Am. Chem. Soc.*, **31,** 490 (1909); Bertsch, German pat., 655,942, *C.A.*, **32,** 3768 (1938).

40*a*. Mandel and Neuberg, *Biochem. Z.*, **71,** 186 (1915); Siebenbürger, U. S. pat., 1,942,577, *C.A.*, **28,** 1716 (1934); Soc. pour l'ind. chim. à Bâle, German pat., 645,608, *C.A.*, **31,** 6377 (1937); French pat., 717,685, *C.A.*, 26, 2749 (1932); French pat., 41,843, *C.A.*, **27,** 4540 (1933). *b*. I. G. Farbenind. A.-G., British pat., 506,049, *C.A.*, **33,** 9323 (1939).

41. Snoddy and Martin, U. S. pats., 2,075,914 and 2,075,915, *C.A.*, **31,** 3596 (1937); British pat., 453,134, *C.A.*, **81,** 1122 (1937); British pat., 479,782, *C.A.*, **32,** 5109 (1938); British pat., 499,542, *C.A.*, **33,** 5095 (1939); Metzger,

German pat., 639,625, *C.A.*, **31**, 3938 (1937); Mills and Wood, U. S. pat., 2,214,254, *C.A.*, **35**, 754 (1941).

42. Butler and Dunnicliff, *J. Chem. Soc.*, **117**, 652 (1920); **123**, 476 (1923).
43. Krafft and Bourgeois, *Ber.*, **25**, 474 (1892).
44. Marx, Brodersen, and Quaedvlieg, German pat., 558,296, *C.A.*, **27**, 731 (1933); Brodersen, German pat., 564,760, *C.A.*, **27**, 997 (1933); U. S. pat., 1,931,962, *C.A.*, **28**, 669 (1934).
45. Cupery, *Ind. Eng. Chem.*, **30**, 627 (1938).
46. Brodersen and Quaedvlieg, German pat., 565,040, *C.A.*, **27**, 997 (1933).
47. Brodersen and Quaedvlieg, German pat., 557,428, *C.A.*, **27**, 731 (1933).
48. Levaillant and Simon, *Compt. rend.*, **169**, 854 (1919); see also Gallotti and Moggi, *Industria chimica*, **8**, 1226 (1933).
49. Boake and Durrans, British pat., 119,250, *C.A.*, **13**, 134 (1919).
50. Bertsch, German pat., 608,413, *C.A.*, **29**, 2665 (1935); see also Harris, U. S. pat., 2,023,387, *C.A.*, **30**, 1465 (1936).
51. Heufser, *Ann.*, **151**, 249 (1869).
52. Kern, German pat., 648,448, *C.A.*, **31**, 8545 (1937).
53. Brodersen and Quaedvlieg, German pat., 606,083, *C.A.*, **29**, 1433 (1935).
54. Kharasch, McNab, and Mayo, *J. Am. Chem. Soc.*, **55**, 2532 (1933).
55. Brooks, *ibid.*, **56**, 1998 (1934).

56*a*. Davis and Schuler, *ibid.*, **52**, 721 (1930); Davis and Crandall, *ibid.*, **52**, 3769 (1930). *b*. Robey, *Ind. Eng. Chem.*, **33**, 1076 (1941).

57. For examples see: Taveau, U. S. pat., 1,810,192, *C.A.*, **25**, 4557 (1931); U. S. pat., 1,845, 007, *C.A.*, **26**, 2200 (1932); Markovich and Piगulevskii, Russ. pat., 25,599, *C.A.*, **26**, 5312 (1932); Perkins and Davies, Canadian pat., 350,409, *C.A.*, **29**, 5127 (1935); Dreyfus, French pat., 782,487, *C.A.*, **29**, 6901 (1935); Brooks, U. S. pat., 2,058,851, *C.A.*, **31**, 109 (1937).
58. N. V. de Bataafsche Petroleum Maatschappij, German pat., 598,538, *C.A.*, **28**, 5831 (1934).
59. van Peski, U. S. pat., 1,944,622, *C.A.*, **28**, 2012 (1934); Dutch pat., 32,446, *C.A.*, **28**, 5076 (1934); U. S. pat., 1,955,908, *C.A.*, **29**, 3349 (1935).
60. Brooks, U. S. pat., 1,940,073, *C.A.*, **28**, 1354 (1934); U. S. pat., 1,970,687, *C.A.*, **28**, 6157 (1934); Young, U. S. pat., 2,047,606, *C.A.*, **30**, 6010 (1936); Le Baron, U. S. pat., 2,028,226, *C.A.*, **30**, 1805 (1936); E. I. du Pont de Nemours and Company, Brit. Pat., 448,457, *C.A.*, **30**, 7126 (1936); Larchar, U. S. pat., 2,099,814, *C.A.*, **32**, 195 (1938); Piगulevskii and Nazarov, *C.A.*, **26**, 4450 (1932).
61. Lacy, U. S. pat., 1,991,948, *C.A.*, **29**, 2174 (1935).
62. Brooks, *J. Am. Chem. Soc.*, **56**, 1998 (1934).
63. Ormandy and Craven, *J. Soc. Chem. Ind.*, **47**, 317T (1928).
64. Ormandy and Craven, *J. Inst. Petroleum Tech.*, **13**, 311, 844 (1927); **17**, 185 (1931); Norris and Davis, *J. Soc. Chem. Ind.*, **48**, 70T (1929); see particularly Ipatieff and Pines, *J. Org. Chem.*, **1**, 465 (1936).
65. Böeseken and Max, *Rec. trav. chim.*, **48**, 486 (1929).
66. Etard, *Compt. rend.*, **86**, 488 (1878); Berthelot, *ibid.*, **118**, 1009 (1894); Erlenmeyer, *Z. Chem.*, (1865) 362; Flavitzky, *Ann.*, **165**, 157 (1873); *Ber.*, **5**, 479 (1872); Osipoff, *Ber.*, **8**, 1240 (1875); Butlerow, *Ann.*, **189**, 75 (1877); Schneider, *Ann.*, **157**, 207 (1871).
67. Norris and Joubert, *J. Am. Chem. Soc.*, **49**, 873 (1927).
68. Michael and Brunel, *Am. Chem. J.*, **41**, 118 (1909).

69. Norris and Davis, *J. Soc. Chem. Ind.*, **48**, 70T (1929); see also Nametkin and Abakumovskaya, *J. Gen. Chem. (U.S.S.R.)*, 6, 1166 (1936); *C.A.*, **31**, 1002 (1937).

70. Krauze and Kogan, *Sintet. Kauchuk*, **3**, No. 5, 29 (1934); *C.A.*, **32**, 5774 (1938).

71*a*. Erlenmeyer and Wanklyn, *Ann.*, **135**, 141 (1865). *b*. Brooks and Humphrey, *J. Am. Chem. Soc.*, 40, 822 (1918). *c*. Nametkin and Rudenko, *J. Gen. Chem.*, 7, 763 (1937); *C.A.*, **31**, 5750 (1937).

72*a*. Michael and Hartman, *Ber.*, **39**, 2149 (1906). *b*. Spiegler and Tinker, *J. Am. Chem. Soc.*, **61**, 940 (1939).

73. Brunel and Probeck, *Am. Chem. J.*, **44**, 437 (1910); Wischnegradsky, *Ann.*, **190**, 328 (1878).

74. Lyons, U. S. pat., 2,094,546, *C.A.*, **31**, 8548 (1937).

75. Bertsch, German pat., 650,758, *C.A.*, **32**, 684 (1938); U. S. pat., 2,027,896, *C.A.*, **30**, 1465 (1936); for sulfonation of squalene see Bunbury, Sexton, and Stewart, U. S. pat., 1,961,683, *C.A.*, **28**, 4929 (1934).

76. Gohr, U. S. pat., 2,103,255, *C.A.*, **32**, 1360 (1938).

77. Engs and Moravec, U. S. pat., 1,967,399, *C.A.*, **28**, 5832 (1934).

78. N. V. de Bataafsche Petroleum Maatschappij, Dutch pat., 42,557, *C.A.*, **32**, 6778 (1938); British pat., 479,137, *C.A.*, **32**, 5109 (1938); see also British pats., 459,078 and 459,079, *C.A.*, **31**, 4015 (1937); Ross, U. S. pat., 2,160,343, *C.A.*, **33**, 7438 (1939).

79. Lacy, U. S. pat., 2,064,667, *C.A.*, **31**, 850 (1937).

80. Cahours and Hofmann, *Ann.*, **102**, 293 (1857); Beilstein and Wiegand, *Ber.*, **18**, 481 (1885).

81. Szymanski, *Ann.*, **230**, 43 (1885).

82*a*. Tiemann and Semmler, *Ber.*, **28**, 2137 (1895). *b*. Grün and Wirth, *Ber.*, **55B**, 2209 (1922).

83*a*. Riess, *Collegium*, 557 (1931); *C.A.*, **26**, 4583 (1932). *b*. Hueter, *Melliand Textilber.*, **13**, 83 (1932). *c*. Schrauth and Hueter, U. S. pat., 2,044,919, *C.A.*, **30**, 5687 (1936); Deutsche Hydrierwerke A.-G., French pat., 776,044, *C.A.*, **29**, 3430 (1935); Bertsch, U. S. pat., 1,968,793, *C.A.*, **28**, 6010 (1934); German pat., 640,997, *C.A.*, **31**, 5377 (1937).

84*a*. Werntz, U. S. pat., 2,104,782, *C.A.*, **32**, 1813 (1938); Schrauth, U. S. pat., 2,079,228, *C.A.*, 31, 4415 (1937); U. S. pat., 2,163,133, *C.A.*, **33**, 8049 (1939). *b*. Guenther *et al.*, U. S. pat., 2,229,649, *C.A.*, **35**, 3009 (1941).

85*a*. Fremy, *Ann.*, **19**, 298 (1836). *b*. Veselý and Majtl, *Bull. soc. chim.*, **39**, 235 (1926). *c*. See Tomecko and Adams, *J. Am. Chem. Soc.*, 49, 522 (1927), for earlier references and a discussion of the structure of the addition products. *d*. Farb. *und* Gerbstoffwerke Carl Flesch, Jr., German pat., 568,209, *C.A.*, **27**, 1895 (1933). *e*. H. Th. Böhme A.-G. Chem. Fabrik, German Pat., 581,658, *C.A.*, **28**, 1211 (1934). *f*. Radcliffe and Gibson, *J. Soc. Dyers Colourists*, **39**, 4 (1923).

86*a*. Nishizawa, *J. Soc. Chem. Ind. Japan*, **39**, Suppl. binding **234** (1936); *C.A.*, **30**, 7372 (1936). *b*. Steiner, *Fettchem. Umschau*, **42**, 201 (1935).

87*a*. Porter *et al.*, *J. Am. Leather Assoc.*, **33**, 509 (1938); *C.A.*, **20**, 302 (1926); Stiasny and Riess, *Collegium*, 498 (1925); Hart, *Am. Dyestuff Reptr.*, **22**, 695 (1933); *Oil & Soap*, **13**, 13 (1936); *Ind. Eng. Chem., Anal. Ed.*, **5**, 413 (1933); *J. Am. Leather Chem. Assoc.*, **28**, 593 (1933); *Am. Dyestuff Reptr.*, **25**, 1221 (1936); *Oil & Soap*, 14, 71 (1937); *Ind. Eng. Chem., Anal. Ed.*, 9, 177

(1937); **11**, 33 (1939); *Rayon Textile Monthly*, **18**, 473 (1937); Jahn, *Seifensieder-Ztg.*, 59, 45 (1932); Pomeranz, *ibid.*, **56**, 95 (1929); Gerber and Sporleder, *Melliand Textilber.*, **20**, 212 (1939); Feigl and Anger, *Mikrochemie*, **15**, 23 (1934); Lindner, *Chem.-Ztg.*, **69**, 388 (1935); Priest *et al.*, *J. Am. Leather Chem. Assoc.*, **24**, 570 (1929); Hart, *Chem. Umschau Fette, Öle, Wachse, Harze*, **36**, 295, 321 (1929); Bauer, *ibid.*, **35**, 290 (1928); **36**, 102 (1929); Riess, *ibid.*, **36**, 77 (1929); *Collegium*, 657 (1929). *b.* For reviews on the preparation, properties, and uses of sulfonated oils, see: Burton and Enna, *J. Intern. Soc. Leather Trades Chem.*, **14**, 459 (1930); Davis, *Am. Dyestuff Reptr.*, **22**, 634 (1933); Mullin and Ramseur, *Textile Colorist*, **53**, 589 (1931); Winokuchi and Toriyama, *J. Soc. Chem. Ind. Japan*, **39**, *Suppl. binding*, 94 (1936); Göllner, *C.A.*, **25**, 2519 (1931); Pomeranz, *Seifensieder-Ztg.*, **58**, 751 (1931); Sokolinski, *Am. Dyestuff Reptr.*, **23**, 265 (1934); Stadler, *Seifensieder-Ztg.*, **58**, 719 (1931); Wechsler, *Chem. Met. Eng.*, **40**, 241 (1933); Lyubarskiĭ, *Chimie & industrie*, **29**, 1406 (1934); Gansel, *Chem. Umschau Fette, Ole, Wachse, Harze*, **36**, 284 (1929); Beyer, *Tiba*, **7**, 1237, 1367 (1929); **8**, 7, 127, 665, 791, 1029 (1930); see also the references on sulfonated castor oil. Some recent patents dealing with the action of sulfuric acid upon oils are: Chem. Fabrik. Stockhausen et Cie, German pat., 561,715, *C.A.*, **27**, 1225 (1933); German pat., 599,837, *C.A.*, **28**, 7573 (1934); German pat., 614,702, *C.A.*, 29, 8381 (1935); French pat., 632,738, *C.A.*, **22**, 3548 (1928); French pat., 804,997, *C.A.*, **31**, 3500 (1937); Chem. Fabrik Milch A.-G., British pat., 293,806, *C.A.*, **23**, 1766 (1929); Böhme, Fettchemie-Ges. m.b.H., German pat., 633,082, *C.A.*, **30**, 7728 (1936); Chem. Fabrik H. Th. Böhme A.-G., German pat., 487,705, *C.A.*, **24**, 2001 (1930); German pat., 581,658, *C.A.*, **28**, 1211 (1934); French pat., 701,187, *C.A.*, **25**, 3862 (1931); Rheiner and Link, U. S. pat., 2,044,400, *C.A.*, **30**, 5442 (1936); Rülke, German pat., 548,189, *C.A.*, **26**, 3691 (1932); I. G. Farbenind. A.-G., British pat., 296,999, *C.A.*, **23**, 2589 (1929); British pat., 288,612, *C.A.*, **23**, 605 (1929); Kaplan, U. S. pat., 2,052,570, *C.A.*, **30**, 7255 (1936); Buch and Brunner, German pat., 566,604, *C.A.*, **27**, 2595 (1933); Erba A.-G., British pat., 292,574, *C.A.*, **23**, 1520 (1929); 294,621, *C.A.*, **23**, 2057 (1929); 296,935, *C.A.*, **23**, 2589 (1929); Seck, U. S. pat., 1,734,050, *C.A.*, **24**, 519 (1930); 1,804,183, *C.A.*, **26**, 3862 (1931). *c.* Bertsch, U. S. pat., 1,918,373, *C.A.*, **27**, 4891 (1933); British pat., 499,203, *C.A.*, **33**, 4703 (1939).

88. Soc. anon. pour l'ind. chem. à St. Denis, French pat., 690,022, *C.A.*, **25**, 1112 (1931); H. Th. Böhme A.-G., French pat., 647,417, *C.A.*, 23, 2589 (1929); British pat., 284,280, *C.A.*, **22**, 4853 (1928); U. S. pat., 1,816,071, *C.A.*, **26**, 5588 (1931); British pat., 351,013, *C.A.*, **26**, 5442 (1932); German pat., 664,387, *C.A.*, **33**, 645 (1939).

89*a*. Bertsch, German pat., 659,528, *C.A.*, **32**, 6773 (1938); U. S. pat., 1,823,815, *C.A.*, **26**, 153 (1932). *b.* For review of earlier literature see: Radcliffe and Medofski, *J. Soc. Dyers Colourists*, **34**, 22 (1918); Jelinek, *Seifensieder-Ztg.*, **60**, 183, 199 (1923); Pomeranz, *Chem. Umschau*, **30**, 133 (1923); Fletcher, *Proc. Am. Assoc. Textile Chem. Colorists*, 203 (1928); *Am. Dyestuff Reptr.*, **17**, 475 (1928); Burton and Enna, *J. Intern. Soc. Leather Trades Chem.*, **14**, 459 (1930); Pomeranz, *Seifensieder-Ztg.*, **61**, 480 (1924); Steiner, *Fettchem. Umschau*, **42**, 201 (1935); Kadmer, *Seifensieder-Ztg.*, **62**, 180, 207 (1935); Stadler, *ibid.*, **68**, 719 (1931); Jahn, *ibid.*, **69**, 45 (1932); Robbe, *Mat. grasses*, **28**,

10886, 10908 (1936); Herbig, *Melliand Textilber.*, **10**, 47 (1929); Conklin, *Color Trade J.*, **14**, 22 (1924). *c.* Recent patents where sulfuric acid is the sulfonating agent are: Bertsch, U. S. pat., 1,801,189, *C.A.*, **25**, 3506 (1931); U. S. pat., 1,816,071, *C.A.*, **25**, 5588 (1931); Kalischer, Günther, Keller, and Hetzer, U. S. pat., 1,835,404, *C.A.*, **26**, 1146 (1932); Kalischer and Biehler, German pat., 606,776, *C.A.*, **29**, 2976 (1935); Stockhausen, Schlotterbeck, Cremer, and Hecking, U. S. pat., 1,849,209, *C.A.*, **26**, 2883 (1932); Soc. anon. pour l'ind. chem. à St. Denis, French pat., 690,022, *C.A.*, **25**, 1112 (1931); Soc. pour l'ind. chem. à Bâle, German pat., 645,608, *C.A.*, **31**, 6377 (1937); German pat., 535,854, *C.A.*, **26**, 1079 (1932); French pat., 745,787, *C.A.*, **27**, 4434 (1933); Swiss pats., 158,547 and 158,823, *C.A.*, **27**, 4945 (1933); Swiss pat., 161,837, *C.A.*, **28**, 487 (1934); Swiss pat., 146,540, *C.A.*, 26, 329 (1932); Rohm and Haas A.-G., German pat., 549,031, *C.A.*, **26**, 3949 (1932); Seck, U. S. pat., 1,804,183, *C.A.*, **25**, 3862 (1931); U. S. pat., 1,734,050, *C.A.*, **24**, 519 (1930); Rozenbroek, U. S. pat., 1,867,954, *C.A.*, **26**, 5223 (1932); N. V. Chem. Fabr. "Servo" and Rozenbroek, Dutch pat., 30,316, *C.A.*, **27**, 6001 (1933); British pat., 293,690, *C.A.*, **23**, 1765 (1929); Chem. Fabrik Stockhausen et Cie, British pat., 293,717, *C.A.*, **23**, 1766 (1929); H. T. Böhme A.-G., British pat., 263,117, *C.A.*, **21**, 4084 (1927).

90a. De Grotte, Keiser, Wirtel, and Monson, *Ind. Eng. Chem.*, *Anal. Ed.*, **3**, 243 (1931); Pomeranz, *Chem. Umschau*, **30**, 133 (1923); *Seifensieder-Ztg.*, **54**, 272, 289 (1927). *b.* Bertsch, German pat., 557,662, *C.A.*, **27**, 612 (1933). *c.* Bertsch, German pat., 634,759, *C.A.*, **31**, 784 (1937).

91. Brachfeld and Smola, Austrian pat., 135,351, *C.A.*, **28**, 1355 (1934).

92. Bertsch, U. S. pat., 1,951,469, *C.A.*, **28**, 3610 (1934); German pat., 669,541, *C.A.*, **33**, 5550 (1939).

93. Cortese, *Ber.*, **62B**, 504 (1929).

94. See, for example, Merley, U. S. pat., 1,809,788, *C.A.*, **25**, 4283 (1931); Nazarov and Gracheva, *C.A.*, **31**, 6187 (1937).

95. Möslinger, *Ber.*, 9, 998 (1876); *Ann.*, **185**, 63 (1877).

96. Bertsch, U. S. pats. 1,968,793, 1,968,794, 1,968,795, 1,968,797, *C.A.*, **28**, 6010 (1934); U. S. pat., 1,993,431, C.A., 29, 2665 (1935); German pat., 608,413, *C.A.*, **29**, 2665 (1935); German pat., 627,055, *C.A.*, **30**, 4239 (1936); German pat., 659,277, *C.A.*, **32**, 5964 (1938); U. S. pat., 2,114,042 and 2,114,043, *C.A.*, **32**, 4251 (1938); Canadian pat., 372,884, *C.A.*, **32**, 4694 (1938); British pats., 351,403 and 351,452, *C.A.*, **26**, 3082 (1932); British pats., 350,080 and 350,432, *C.A.*, 26, 2026 (1932); I. G. Farbenind. A.-G., British pat., 352,989, *C.A.*, **26**, 3388 (1932); British pat., 354,217, *C.A.*, **26**, 3949 (1932); Böhme Fettchemie Ges. m. b. H., German pat., 628,064, *C.A.*, **30**, 4591 (1936); French pat., 718,395, *C.A.*, **26**, 2988 (1932); N. V. Bataafsche Petroleum Maatschappij, British pat., 486,707, *C.A.*, **32**, 9382 (1938); Deutsche Hydrierwerke A.-G., British pat., 463,544, *C.A.*, **31**, 5815 (1937); Bertsch, U. S. pat., 2,047,612, *C.A.*, **30**, 6010 (1936); McAllister, Duncan, and Quimby, U. S. pat., 2,121,485, *C.A.*, **32**, 6362 (1938); Schütte, German pat., 664,176, *C.A.*, **33**, 782 (1939); Beller and Owen, U. S. pat., 2,149,265, *C.A.*, **33**, 4271 (1939); Mills, British pat., 499,373, *C.A.*, **33**, 4703 (1939); Lenher and Arnold, U. S. pat., 2,139,277, *C.A.*, **33**, 2250 (1939); Schrauth, German pat., 542,048, *C.A.*, **26**, 3082 (1932).

97. Killeffer, *Ind. Eng. Chem.*, **25**, 138 (1933); Lenher, *Am. Dyestuff Reptr.*, **22**, 13 (1933); *ibid.*, **21**, 693 (1932); *Chem. Markets*, **32**, 127 (1933);

Bruinier, *Textile Colorist,* **55,** 456 (1933); Welwart, *Seifensieder-Ztg.,* 60, 401, 617 (1933); Lindner, *ibid.,* **62,** 257, 277, 299 (1935); Biffen and Snell, *Ind. Eng. Chem., Anal. Ed.,* **7,** 234 (1935); Fischer, *Kunstseide,* **19,** 186 (1937); Lederer, *Kolloid-Z.,* **75,** 236 (1936); Kadmer, *Seifensieder-Ztg.,* **62,** 180, 207 (1935); Cupples, U. S. Dept. Agr. Bur. Entomol. Plant Quarantine E 426, 24 pp. (1938); Tisdale, *Rev. Applied Mycol.,* **14,** 598 (1935); Tyler, *Soap,* **10,** 21, 65 (1934); Evans, *J. Soc. Dyers & Colourists,* **51,** 233 (1935); Richardson, *Oil & Soap,* **11,** 10 (1934); Pomeranz, *Seifensieder-Ztg.,* **59,** 293 (1932); Sisley, *Rev. gén. mat. color,* **43,** 96 (1939).

98. Steindorff, Lange, and Horst, U. S. pat., 2,062,842, *C.A.,* **31,** 785 (1937); Wilkes and Wickert, *Ind. Eng. Chem.,* **29,** 1234 (1937); U. S. pat., 2,088,020, *C.A.,* **31,** 6772 (1937); U. S. pat., 2,088,021, *C.A.,* **31,** 6773 (1937); Wickert, U. S. pat., 2,088,019, *C.A.,* **31,** 6769 (1937); Wickert and Freure, U. S. pats., 2,088,018 and 2,088,014, *C.A.,* **31,** 6770 (1937); Wickert and Carter, U. S. pat., 2,088,017, *C.A.,* 31, 6770 (1937); Wickert, U. S. pats. 2,088,015 and 2,088,016, *C.A.,* **31,** 6673 (1937); I. G. Farbenind. A.-G., British pat., 477,499, *C.A.,* **32,** 3862 (1938); Law and McNamee, U. S. pat., 2,088,027, *C.A.,* **31,** 6673 (1937).

99. Schrauth, German pat., 662,092, *C.A.,* **32,** 7612 (1938); Buc, U. S. pat., 2,139,669, *C.A.,* **33,** 2249 (1939).

100. Waldmann and Chwala, French pat., 779,503, *C.A.,* **29,** 5546 (1935); Harris, U. S. pat., 2,023,387, *C.A.,* **30,** 1465 (1936).

101. Ulrich and Nüsslein, German pat., 634,032, *C.A.,* **30,** 8445 (1936); Ulrich and Körding, German pat., 633,334, *C.A.,* **30,** 7584 (1936); U. S. pat., 1,931,806, *C.A.,* **28,** 670 (1934); Katz, U. S. pat., 2,216,617, *C.A.,* **35,** 830 (1941).

102. Knight and Piggott, U. S. pat., 2,118,089, *C.A.,* **32,** 5639 (1938).

103. Baldwin and Piggott, U. S. pat., 2,100,297, *C.A.,* **32,** 683 (1938).

104. Soc. pour l'ind. chim. à Bâle, British pat., 431,662, *C.A.,* **29,** 8179 (1935); Bertin, *C.A.,* **32,** 7651 (1938).

105. Henkel et Cie G.m.b.H., French pat., 794,422, *C.A.,* **30,** 4592 (1936).

106. I. G. Farbenind. A.-G., German pat., 642,885, *C.A.,* **31,** 5904 (1937).

107. I. G. Farbenind. A.-G., French pat., 796,059, *C.A.,* **30,** 5689 (1936).

108. Soc. pour l'ind. chim. à Bâle, British pat., 449,043, *C.A.,* **30,** 7727 (1936); Ulrich, Koerding, and Nuesslein, U. S. pat., 2,063,963, *C.A.,* **31,** 783 (1937); Henkel et Cie, French pat., 801,683, *C.A.,* **31,** 482 (1937); British pat., 461,957, *C.A.,* **31,** 5382 (1937); Bruson, U. S. pat., 2,106,716, *C.A.,* **32,** 2651 (1938); Schrauth, German pat., 635,903, *C.A.,* **31,** 784 (1937); Schenk, U. S. pat., 2,114,256, *C.A.,* **32,** 4252 (1938); Höchtlen and Cremer, German pat., 656,000, *C.A.,* **32,** 3863 (1938); Benner, U. S. pat., 2,091,956, *C.A.,* **31,** 7562 (1937); Bertsch, U. S. pat., 1,951,784, *C.A.,* **28,** 3541 (1934); U. S. pat., 2,007,492, *C.A.,* **29,** 5952 (1935); German pat., 550,912, *C.A.,* **26,** 4824 (1932); German pat., 655,942, *C.A.,* **32,** 3768 (1938); I. G. Farbenind. A.-G., British pat., 407,990, *C.A.,* **28,** 5469 (1934); U. S. pat., 1,993,375, *C.A.,* **29,** 2626 (1935); Luther, U. S. pat., 1,908,376, *C.A.,* **27,** 3841 (1933); I. G. Farbenind. A.-G., German pat., 640,581, *C.A.,* **31,** 5378 (1937); Deutsche Hydrierwerke A.-G., British pat., 463,544, *C.A.,* **31,** 5815 (1937); Bertsch, German pat., 652,433, *C.A.,* **32,** 1814 (1938); Ulrich and Koerding, U. S. pat., 2,037,442, *C.A.,* **30,** 4019 (1936); Lederer, British pat., 483,301, *C.A.,* **32,** 7165 (1938); I. G. Farbenind. A.-G., British pat.,

481,557, *C.A.*, **32**, 6362 (1938); 427,943, *C.A.*, 29, 6772 (1935); Abramovitch, *Tiba*, **11**, 803 (1933); *C.A.*, **28**, 2558 (1934); Dreyfus, French pat., 636,488, *C.A.*, **23**, 1140 (1929); I. G. Farbenind. A.-G., French pat., 836,639, *C.A.*, **33**, 5551 (1939); British pat., 500,032, *C.A.*, **33**, 5549 (1939); Harris, British pat., 488,490, *C.A.*, **33**, 279 (1939); Kirstahler and Kaiser, German pat., 676,273, *C.A.*, **33**, 6344 (1939); Harris, U. S. pat., 2,155,899, *C.A.*, **33**, 5948 (1939); I. G. Farbenind. A.-G., British pat., 499,022, *C.A.*, **33**, 4702 (1939); Oranienburger, Chem. Fabrik. A.-G., German pat., 664,514, *C.A.*, **33**, 280 (1939); Bruson and Stein, U. S. pat., 2,143,759, *C.A.*, **33**, 3032 (1939); Engel, German pat., 663,953, *C.A.*, **33**, 280 (1939); Rosenhauer, German pat., 675,723, *C.A.*, **33**, 6996 (1939); Elbel, German pat., 675,934, *C.A.*, **33**, 6996 (1939); I. G. Farbenind. A.-G., British pat., 492,905, *C.A.*, **33**, 1841 (1939); Zimmerman, Canadian pat., 377,543, *C.A.*, **33**, 2249 (1939); N. V. Chemische Fabriek "Servo" and Rozenbroek, British pat., 489,026, *C.A.*, **33**, 282 (1933); Flett, U. S. pat., 2,136,379, *C.A.*, **33**, 1416 (1939); Canadian pat., 376,873, *C.A.*, **33**, 1841 (1939); I. G. Farbenind. A.-G., British pat., 499,022, *C.A.*, **33**, 4702 (1939); French pat., 836,639, *C.A.*, **33**, 5551 (1939); British pat., 500,615, *C.A.*, **33**, 5947 (1939); British pat., 501,004, *C.A.*, **33**, 5948 (1939); Henkel et Cie G.m.b.H., British pat., 501,408, *C.A.*, **33**, 6482 (1939); Alframine Corp., French pat., 838,169, *C.A.*, **33**, 7439 (1939); I. G. Farbenind. A.-G., British pat., 512,022, *C.A.*, **35**, 235 (1941).

109. Nishizawa and Tomitsuka, *J. Soc. Chem. Ind. Japan*, **35**, Suppl. binding 548 (1932); Nishizawa, *ibid.*, **35**, 550 (1932).
110. Ueno, Yokoyama, and Iwakura, *J. Soc. Chem. Ind. Japan*, Suppl. binding 603 (1938); *C.A.*, **30**, 892 (1936).
111. Tyler, *Soap*, **10**, 21, 65 (1934).
112. Lottermoser and Stoll, *Kolloid-Z.*, **63**, 49 (1933).
113. Smith and Jones, *J. Phys. Chem.*, **38**, 243 (1934).
114. Kling and Püschel, *Melliand Textilber.*, **15**, 21 (1934).

115*a*. Lindner, Russe, and Beyer, *Fettchem, Umschau*, **40**, 93 (1933). *b*. Jahn, *Chem.-Ztg.*, **57**, 383 (1933). *c*. Biffen and Snell, *Ind. Eng. Chem., Anal. Ed.*, **7**, 234 (1935).

116. Brooks, U. S. pat., 1,944,400, *C.A.*, **28**, 2013 (1934).
117. Stuart, U. S. pat., 2,013,453, *C.A.*, **29**, 6901 (1935); Engs and Moravec, U. S. pat., 1,955,417, *C.A.*, **28**, 3741 (1934); Sargent, British pat., 427,223, *C.A.*, **29**, 6245 (1935); Standard Oil Company of California, British pat., 471,667, *C.A.*, **32**, 1277 (1938); Sargent, U. S. pat., 2,045,616, *C.A.*, **30**, 5591 (1936); Shtakelberg, *C.A.*, **29**, 6035 (1935).
118. Erlenmeyer and Kriechbaumer, *Ber.*, **7**, 699 (1874); Guyot and Simon, *Compt. rend.*, **169**, 655 (1919).
119. Claësson, *J. prakt. Chem.*, **[2] 19**, 231 (1879).
120. Hennion, Hinton, and Nieuwland, *Proc. Indiana Acad. Sci.*, **42**, 109 (1933); *C.A.*, **27**, 5716 (1933); I. G. Farbenind. A.-G., French pat., 718,181, *C.A.*, **26**, 2988 (1932).
121. Otto, *Ann.*, **284**, 300 (1895).
122. Lauterbach, *Ber.*, **11**, 1225 (1878); Rây and Neogi, *J. Chem. Soc.*, 89, 1900 (1906); Neogi, *ibid.*, **105**, 2371 (1914).
123. Krause, Swiss pat., 75,523, *C.A.*, **12**, 41 (1918).
124. Pelouze, *Ann.*, **10**, 249 (1834); Linnemann, *Ann.*, **148**, 252 (1868); Wade, *J. Chem. Soc.*, **81**, 1598 (1902).

125. Gregory, *Ann.*, **15**, 239 (1835); Klason, *Ber.*, **20**, 3413 (1887).
126. Liebig, *Ann.*, **11**, 14 (1834); Michler, *Ann.*, **176**, 181 (1875).
127. Gray and Gutekunst, *J. Am. Chem. Soc.*, **42**, 856 (1920).
128. Wegscheider and Schreiner, *Monatsh.*, **40**, 328 (1919).
129. I. G. Farbenind. A.-G., French pat., 718,672, *C.A.*, **26**, 3261 (1932).
130. Claësson, *J. prakt. Chem.*, [2] **19**, 231 (1879); Levaillant and Simon, *Compt. rend.*, **169**, 140 (1919).
131. Guyot and Simon, *ibid.*, **169**, 655 (1919).
132. Oddo and Scandola, *Gazz. chim. ital.*, **40**, II, 163 (1910); *C.A.*, **5**, 1744 (1911).
133. Werner, *J. Chem. Soc.*, **105**, 2762 (1914).
134. Denham and Knapp, *J. Chem. Soc.*, **117**, 236 (1920).
135. Bertsch and Stober, U. S. pat., 2,104,728, *C.A.*, **32**, 1813 (1938).
136. Guyot and Simon, *Compt. rend.*, **168**, 1054, 1204 (1919).
137. Villiers, *ibid.*, **90**, 1291 (1880).
138. Scholvien, *Chem. Zentr.*, II, 2, 782 (1890).
139. Köhler, *Ber.*, **11**, 1926 (1878).
140. Nef, *Ann.*, **318**, 40 (1901); Biron, *Chem. Zentr.*, I, 855 (1898).
141. Wurtz, *Ann.*, **93**, 123 (1855).
142. Engelhardt and Lommel, U. S. pat., 1,770,734, *C.A.*, **24**, 4520 (1930).
143. Dumas and Peligot, *Ann.*, **15**, 40 (1835); Kane, *Ann.*, **20**, 190 (1836).
144. Kremann and Neumann, *Monatsh.*, **31**, 1051 (1910).
145. Merck, German pat., 133,542, *Chem. Zentr.*, II, 314 (1902).
146. Hantzsch, *Z. physik. Chem.*, **65**, 56 (1908).
147. Ostwald, *ibid.*, **1**, 76 (1887).
148. Levaillant and Simon, *Compt. rend.*, **169**, 140, 234 (1919).
149. Boulin and Simon, *ibid.*, **169**, 339 (1919).
150. Guyot and Simon, *ibid.*, **169**, 435 (1919); for the reaction with sodium fluoride see Groggins, "Unit Processes in Organic Syntheses," McGraw-Hill Book Company, New York, 1935, p. 142.
151. Benedikt and Bamberger, *Monatsh.*, **12**, 1 (1891).
152. Hiers and Hager, *Org. Syntheses*, **9**, 12 (1929), John Wiley & Sons, New York. See also under methyl sulfate.
153. Zawidski and Zaykowski, *Anzeiger Akad. Wiss. Krakau*, 75–158 (1916); *C.A.*, **11**, 2294 (1917).
154. Linhart, *Am. J. Sci.*, **34**, 539 (1912).
155. Linhart, *ibid.*, **34**, 289 (1912).
156. Linhart, *ibid.*, **35**, 283 (1913).
157. Meyer and Schramm, *Z. anorg. allgem. Chem.*, **206**, 24 (1932).
158. Behrend, *Ber.*, **9**, 1334 (1876); *J. prakt. Chem.*, [2] **15**, 32 (1877).
159. Kraft and Alekseev, *J. Gen. Chem.* (*U.S.S.R.*), **2**, 726 (1932); C.A., **27**, 2426 (1933).
160. Sandmeyer, *Ber.*, **19**, 861 (1886).
161. Guyot and Simon, *Compt. rend.*, **170**, 326 (1920).
162. Frèrejacque, *ibid.*, **183**, 607 (1926).
163. Levaillant, *ibid.*, **200**, 1053 (1935).
164. Traube, *Z. angew. Chem.*, **38**, 441 (1925).
165. Delépine and Demars, *Bull. sci. pharmacol.*, **30**, 577 (1923).
166. Fuchs and Katscher, *Ber.*, **60B**, 2288 (1927).
167. Dabit, *Ann. chim.*, **34**, 289 (1798); **43**, 101 (1802); *Ann. chim. phys.*, **13**, 62 (1820); Serturner, *Gilberts Ann.*, **60**, 53 (1818); **64**, 67 (1820); Vogel, *ibid.*,

63, 81 (1819); Heeren, *Pogg. Ann.*, **7**, 193 (1826); Hennell, *Phil. Trans. Roy. Soc.*, **116**, III, 240 (1826); **118**, II, 365 (1828); *Pogg. Ann.*, **7**, 110 (1826); 9, 12 (1827); 14, 273 (1828); *Phil. Mag.*, 68, 354 (1826); *Ann. chim. phys.*, **39**, 154 (1828); Dumas and Boullay, *ibid.*, **36**, 310 (1827); **37**, 15 (1828); *Pogg. Ann.*, **12**, 93, 430 (1828); Serrulas, *ibid.*, **15**, 20 (1829); Liebig and Wöhler, *ibid.*, **22**, 487 (1831); Magnus, *ibid.*, **27**, 367 (1833); *Ann.*, 6, 152 (1833); Liebig, *Ann.*, 9, 17 (1834); **13**, 32 (1835); Marchand, *Ann.*, **12**, 248 (1834); **13**, 28 (1835); Limousin, *J. pharm. chim.*, [4] **15**, 271 (1871).

168. Berthelot, *Bull. soc. chim.*, [2] **19**, 227, 295 (1873).
169. Kremann, *Monatsh.*, **31**, 245, 1031 (1910).
170. Evans and Albertson, *J. Am. Chem. Soc.*, **39**, 456 (1917).
171. Dunnicliff and Butler, *J. Chem. Soc.*, **119**, 1384 (1921).
172. Zaitschek, *Z. physik. Chem.*, **24**, 1 (1897).
173. Kailan, *Monatsh.*, **30**, 1 (1909).
174. Marchand, *Pogg. Ann.*, **41**, 603 (1837).
175. Hamid, Singh, and Dunnicliff, *J. Chem. Soc.*, 1098 (1926).
176. Kremann, *Monatsh.*, **31**, 211 (1910).

177*a*. Hennell, *Pogg. Ann.*, **14**, 282 (1828); *Proc. Roy. Soc. (London)*, **118**, 365 (1828). *b*. Berthelot, *Compt. rend.*, **40**, 102 (1855); *Ann. chim. phys.*, [3] **43**, 385 (1855). *c*. Gorgainow, *Ber.*, 6, 196 (1873). *d*. Fritzsche, *Chem. Ind. (Germany)*, **20**, 266 (1897); *ibid.*, **21**, 33 (1898); *Z. angew. Chem.*, 9, 456 (1896).

178. Plant and Sidgwick, *J. Soc. Chem. Ind.*, 40, 14T (1921).
179. Damiens, *Compt. rend.*, **175**, 585 (1922); Dalin and Gutyrya, *C.A.*, **33**, 7271 (1939).

180*a*. Dreisbach, U. S. pat., 2,210,316, *C.A.*, **35**, 134 (1941). *b*. Loisy, *Compt. rend.*, **170**, 50 (1920).

181. Lommell and Engelhardt, *Ber.*, **57B**, 848 (1924); U. S. pat., 1,458,646, *C.A.*, **17**, 2587 (1923); British pat., 185,757, *C.A.*, **17**, 771 (1923); Gluud and Schneider, *Ber.*, **57B**, 254 (1924).
182. Loisy and Damiens, *Chim. ind.*, Special No., p. 664 (May, 1923).
183. N. V. de Bataafsche Petroleum Maatschappij, British pats., 336,603 and 336,633, *C.A.*, **25**, 1843 (1931).
184. Strahler and Hachtel, *Brennstoff-Chem.*, **15**, 166 (1934).
185. Maimeri, *C.A.*, **19**, 1402 (1925).
186. Ellis, "The Chemistry of Petroleum Derivatives," Chemical Catalog Company, New York, 1934, p. 332.
187. Magnus, *Pogg. Ann.*, **27**, 386 (1833); Scholvien, *Pharm. Zentralhalle*, **31**, 605 (1890); *Chem. Ind. (Germany)*, **14**, 114 (1891); *Apoth. Ztg.*, 5, 607 (1890).
188. Oddo and Scandola, *Gazz. chim. ital.*, 40, II, 163 (1910); *C.A.*, **5**, 1744 (1911).
189. I. G. Farbenind. A.-G., French pat., 718,181, *C.A.*, **26**, 2988 (1932); Schumann and Ufer, U. S. pat., 1,961,987, *C.A.*, **28**, 4748 (1934).
190. Evans and Albertson, *J. Am. Chem. Soc.*, **39**, 456 (1917).
191. Kremann, *Monatsh.*, **31**, 165 (1910).
192. Drushel and Linhart, *Am. J. Sci.*, **32**, 51 (1911).
193. Mayer, *Ber.*, **23**, 909 (1890).
194. Blacher, *Ber.*, **28**, 2357 (1895); Titherly, *J. Chem. Soc.*, **79**, 399 (1901).
195. Erlenmeyer, *Jahresbericht*, 238 (1874).

196. Köhler, *Ber.*, **11**, 1926 (1878).
197. Passon, *Ber.*, **24**, 1678 (1891).
198. Kolbe, *J. prakt. Chem.*, [2] **27**, 425 (1883); **28**, 62 (1883).
199. Nadler, *Ann.*, **116**, 173 (1860).
200. Köhler, *Ber.*, **11**, 1929 (1878).
201. Bamberger, *Ber.*, **40**, 1906 (1907); Bamberger and Frei, *Ber.*, **40**, 1932 (1907); Bamberger and Brun, *Ber.*, **40**, 1949 (1907).
202. Renard, *Ann. chim. phys.*, [5] **16**, 289 (1879); *Compt. rend.*, **90**, 531 (1880).
203. Traube, German pat., 342,898, *Frdl.*, **13**, 52; U. S. pat., 1,510,425, *C.A.*, **19**, 76 (1925).
204*a*. Kuhlmann, *Ann.*, **33**, 108 (1840). *b*. Williamson, *J. Chem. Soc.*, **10**, 97 (1857); *J. prakt. Chem.*, **73**, 73 (1858). *c*. Purgold, *Ann.*, **149**, 124 (1869); *Ber.*, **6**, 502 (1873).
205. Nef, *Ann.*, **318**, 40 (1901).
206*a*. Bushong, *Am. Chem. J.*, **30**, 212 (1903). *b*. Willcox, *ibid.*, **32**, 446 (1904).
207*a*. Müller, *Ber.*, **6**, 228 (1873). *b*. Traube and Justh, *Brennstoff-Chem.*, **4**, 150 (1923); *C.A.*, **17**, 3858 (1923).
208. Baumstarck, *Z. Chem.*, 567 (1867).
209. Willcox, *Am. Chem. J.*, **32**, 465 (1904).
210*a*. Traube, *Z. angew. Chem.*, **38**, 441 (1925). *b*. Binkley and Degering, *Proc. Indiana Acad. Sci.*, **49**, 117 (1939).
211. Wenghöffer, *J. prakt. Chem.*, [2] **31**, 1803 (1885).
212. Wagner, *Ber.*, **19**, 1157 (1886).
213. Bayer and Co., German pat., 75,456, *Frdl.*, **4**, 1112; German pat., 73,165, *Frdl.*, **3**, 865.
214*a*. Levaillant, *Compt. rend.*, **189**, 465 (1929). *b*. Isham and Spring, U. S. pat., 1,918,967, *C.A.*, **27**, 4815 (1933).
215. Levaillant, *Compt. rend.*, **197**, 648 (1933).
216. Schmidt, *Chem. Ind. Kolloide*, 576 (1870).
217. Bolland, *Monatsh.*, **31**, 392 (1910).
218. Ostwald, *Z. physik. Chem.*, **1**, 76 (1887).
219*a*. Steinkopf, Mieg, and Herold, *Ber.*, **53B**, 1144 (1920). *b*. Levaillant, *Compt. rend.*, **187**, 730 (1928).
220. Lieben and Rossi, *Ann.*, **165**, 116 (1873).
221. Brodersen and Quaedvlieg, German pat., 557,428, *C.A.*, **27**, 731 (1933).
222. Gerhardt, this laboratory, unpublished results.
223. Nef, *Ann.*, **318**, 49 (1901).
224. Krafft and Bourgeois, *Ber.*, **25**, 475 (1892).
225. Cahours, *Ann.*, **30**, 291 (1839); Kekulé, *Ann.*, **75**, 277 (1850).
226. Pasteur, *Ann.*, **96**, 256 (1855); *Compt. rend.*, **41**, 296 (1855).
227. Balbiano, *Gazz. chim. ital.*, **6**, 229 (1867); *Ber.*, **9**, 1437 (1876).
228. Marckwald, *Ber.*, **35**, 1598 (1902); **37**, 1042 (1904); Marckwald and Nolda, *Ber.*, **42**, 1587 (1909).
229. Neuberg, *Biochem. Z.*, **76**, 166 (1916).
230. Kolshorn, German pat., 341,607, *Chem. Zentr.*, IV, 1176 (1921).
231. Bauer and Poethke, *J. prakt. Chem.*, [2] **126**, 296 (1930).
232. Nadler, *Ann.*, **116**, 173 (1860).
233. Ormandy and Craven, *J. Inst. Petroleum Tech.*, **13**, 311, 844 (1927); *J. Soc. Chem. Ind.*, **47**, 317T (1928); see, however, Norris and Davis, *ibid.*, **48**, 70T (1929).

234. Mann and Williams, U. S. pat., 1,365,043, *C.A.*, **16**, 944 (1921); *J. Soc. Chem. Ind.*, **40**, 162A (1921); N.-V. de Bataafsche Petroleum Maatschappij, French pat., 704,876, *C.A.*, **26**, 4557 (1931); German pat., 562,825, *C.A.*, **27**, 997 (1933).

235. Brooks and Cardarelli, U. S. pat., 1,919,617, *C.A.*, **27**, 4818 (1933).

236. Deanesley, U. S. pat., 1,955,873, *C.A.*, **28**, 4070 (1934).

237. Merley, U. S. pat., 1,897,812, *C.A.*, **27**, 2696 (1933).

238. Woolcock, U. S. pat., 1,938,162, *C.A.*, **28**, 1058 (1934).

239. Piguleyskiĭ and Rudakova, *C.A.*, **31**, 6187 (1937).

240. Spiegel and Dobrin, *Chem. Zentr.*, I, 112 (1896).

241. Meth, *Ber.*, **40**, 696 (1907).

242. Taveau, U. S. pat., 1,810,192, *C.A.*, **25**, 4557 (1931).

243. Taveau, U. S. pat., 1,845,007, *C.A.*, **26**, 2200 (1932).

244. Markovich and Piguleyskiĭ, Russian pat., 25,599, *C.A.*, **26**, 5312 (1932).

245. Weizmann and Legg, U. S. pat., 1,408,320, *C.A.*, **16**, 1593 (1922); Brooks, U. S. pat., 1,879,599, *C.A.*, **27**, 312 (1933); U. S. pat., 1,970,687, *C.A.*, **28**, 6157 (1934); King, *J. Chem. Soc.*, **115**, 1404 (1919); Newmann, *Can. Chem. J.*, **4**, 47 (1920); *C.A.*, **14**, 1120 (1920).

246. Reference 186, p. 378.

247. Krüger, *Ber.*, **26**, 1203 (1893).

248. Bouis, *Compt. rend.*, **38**, 935 (1869).

249. Mamontoff, *Chem. Zentr.*, II, 408 (1897).

250. Erickson, this laboratory, unpublished results.

251. Steinkopf, Mieg, and Herold, *Ber.*, **63B**, 1144 (1920).

252. Levaillant, *Compt. rend.*, **187**, 730 (1928).

253. Isham and Spring, U. S. pat., 1,918,967, *C.A.*, **27**, 4815 (1933).

254. Swarts, *Compt. rend.*, **197**, 1261 (1933).

255. Moness and Christiansen, *J. Am. Pharm. Assoc.*, **23**, 904 (1934).

256. Levaillant, *Compt. rend.*, **197**, 335 (1933).

257. Thieme, *J. prakt. Chem.*, [2] **85**, 284 (1912).

258*a*. Wenker, *J. Am. Chem. Soc.*, **57**, 2328 (1935). *b*. Rollins and Calderwood, *ibid.*, **60**, **2312** (1938). *c*. Fränkel and Cornelius, *Ber.*, **51**, 1660 (1918). *d*. Rollins and Calderwood, *J. Am. Chem. Soc.*, **60**, **2751** (1938). *e*. Garelli and Racciu, *Atti accad. sci. Torino*, **69**, **162** (1934).

259. Seck and Dittmar, *Fettchem. Umschau*, **40**, 146 (1933); *C.A.*, **27**, 5306 (1933).

260*a*. Grün and Woldenberg, *J. Am. Chem. Soc.*, **31**, **490** (1909). *b*. Winckler, U. S. pat., 1,912,814, *C.A.*, **27**, 4244 (1933).

261. Cocker, Davies, and Hill, British pat., 409,733, *C.A.*, **28**, 6157 (1934).

262*a*. I. G. Farbenind. A.-G., British pat., 348,040, *C.A.*, **26**, 2026 (1932). *b*. Werntz, U. S. pat., 2,225,673, *C.A.*, **36**, **2156** (1941).

263*a*. Farb- und Gerbstoff Werke, Carl Flesch, Jr., German pat., 557,088, *C.A.*, **27**, 308 (1933); British pat., 287,076, *C.A.*, **23**, 395 (1929). *b*. Gerrard, *J. Chem. Soc.*, 218 (1940).

264. Werntz, U. S. pats., 2,121,616, and 2,121,617, *C.A.*, **32**, 6362 (1938).

265. Verhulst, *Bull. soc. chim. Belg.*, **40**, 475 (1931).

266*a*. Nishizawa and Winokuti, *Chem. Umschau Fette, Öle, Wachse Harze*, **36**, 79 (1929). *b*. Nishizawa, Winokuti, and Kikuti, *Tech. Repts. Tôhoku Imp. Univ.*, **10**, 93 (1931); *J. Soc. Chem. Ind. Japan*, **32**, Suppl. binding 277B (1929). *c*. Seck, *Fettchem. Umschau*, **41**, 61 (1934).

267*a*. Cannizzaro, *Ann.*, 92, 114 (1854); Senderens, *Compt. rend.*, **182**, 612 (1926); see also Hanztsch, *Ber.*, **31**, 184 (1898). *b*. Verley, *Bull. soc. chim.*, [3] **25**, 46 (1901).

268. Delépine, *Compt. rend.*, **129**, 832 (1899); *Bull. soc. chim.*, [3] **21**, 1059 (1899).

269. Ullmann, *Ber.*, **35**, 1813 (1902); Hemilian, *Ber.*, **7**, 1207 (1874); Frey, *Ber.*, **28**, 2517 (1895).

270. Norris, *Am. Chem. J.*, 38, 638 (1907).

271. Emde, *Helv. Chim. Acta*, **12**, 399 (1929).

272. Iwamoto, *Bull. Chem. Soc. Japan*, **11**, 201 (1936); *C.A.*, 30, 5976 (1936); Fairweather and Thomas, U. S. pat., 1,949,299, *C.A.*, **28**, 2725 (1934).

273. Albrecht, German pat., 526,800, *C.A.*, 25, 4891 (1931).

274. Burkhardt, *J. Chem. Soc.*, 2387 (1930).

275. Chem. Fabr. von Heyden, German pat., 208,790, *Chem. Zentr.*, I, 1521 (1909).

276. Bouchardat and Lafont, *Compt. rend.*, **125**, 111 (1897).

277. Mandell and Neuberg, *Biochem. Z.*, **71**, 186 (1915); Sobel and Spoerri, *J. Am. Chem. Soc.*, **63**, 1259 (1941).

278. Oppenheim, *Ber.*, **3**, 735 (1870).

279. Simpson, *Ann.*, **112**, 146 (1859).

280. Claësson, *J. prakt. Chem.*, [2] 20, 1 (1879).

281. Grün, *Ber.*, **52B**, 261 (1919).

282. Henry, *Ber.*, **4**, 703 (1871).

283. Grün and Theimer, *Ber.*, **40**, 1792 (1907); Senter, *Proc. Chem. Soc.*, **24**, 89 (1908).

284. Gustavson and Demjanoff, *J. prakt. Chem.*, [2] **38**, 201 (1888).

285. Pelouze, *Ann.*, 19, 211 (1836); 20, 48 (1836); *Chem. Zentr.*, 15 (1837).

286. Schmeltzer and Aschman, German pat., 86,334, *Ber.*, 29 **Ref.**, 476 (1876).

287. Thieme, *J. prakt. Chem.*, [2] 85, 299 (1912).

288. Grün, *Ber.*, **38**, 2284 (1905); Grün and Schacht, *Ber.*, **40**, 1781 (1907).

289. Thieme, *Koninkl. Akad. Wetenschappen Amsterdam*, **10**, 855 (1909); *C.A.*, **4**, 754 (1910).

290. Thieme, *J. prakt. Chem.*, [2] **85**, 284 (1912).

291. Bertsch, German pat., 550,912, *C.A.*, 26, 4824 (1932).

292. Favre, *Ann. chim. phys.*, [3] **11**, 77 (1844); Knop and Schnedermann, *Ann.*, **51**, 132 (1844); Bloor, *J. Am. Chem. Soc.*, **35**, 784 (1913).

293. Soda and Nagai, *J. Chem. Soc. Japan*, **56**, 1258 (1935).

294. Gebauer-Fülnegg, Stevens, and Krug, *Monatsh.*, **50**, **324** (1928).

295. Neuberg and Liebermann, *Biochem. Z.*, **121**, 326 (1921); Soda, *ibid.*, **135**, 621 (1923).

296. Soda, *Bull. Chem. Soc. Japan*, **8**, 37 (1933); *C.A.*, 27, 2428 (1933); Percival and Soutar, *J. Chem. Soc.*, **1475** (1940).

297. Soda and Hattori, *Proc. Imp. Acad. Tokyo*, **7**, 269 (1931).

298. Levene and Meyer, *J. Biol. Chem.*, **53**, **437** (1922); Ohle, *Biochem. Z.*, **136**, 428 (1923).

299. Ohle, *Biochem. Z.*, **131**, 601 (1922).

300. Ohle and Bourjou, *Ber.*, **58B**, 721 (1925).

301. Ohle, Marecek, and Bourjau, *Ber.*, **62B**, 833 (1929).

302. Neuberg and Pollak, *Ber.*, **43**, 2060 (1910).

303. Soda, *Biochem. Z.*, **135**, 621 (1923).

304. Soda, *Bull. Chem. Soc. Japan*, 9, 1 (1934).

305. Takahashi and Shirahama, *J. Faculty Agr. Hokkaido Imp. Univ.*, **35**, 101 (1934); *C.A.*, **28**, 5412 (1934).
306. Hoffman and Gortner, *J. Biol. Chem.*, **65**, 371 (1925).
307. Hönig and Schubert, *Monatsh.*, **6**, 708 (1885).
308. Gebauer-Fülnegg, Stevens, and Dingler, *Ber.*, **61B**, 2000 (1928).
309. Traube, Blaser, and Lindemann, *Ber.*, **65B**, 603 (1932).
310. Traube, Blaser, and Grunert, *Ber.*, **61B**, 754 (1928); Traube, French pat., 657,204, *C.A.*, **23**, 4342 (1929).
311. Samec, *Monatsh.*, **53** and **54**, 852 (1929).
312. Tamba, *Biochem. Z.*, **141**, 274 (1923).
313. Baumann, *Ber.*, **9**, 54, 1389 (1876).
314. Baumann, *Ber.*, **9**, 1715 (1876); **11**, 1907 (1878); Tiemann and Koppe, *Ber.*, **14**, 2019 (1881); Heymann and Königs, *Ber.*, **19**, 3310 (1886); Nietzki, *Ber.*, **15**, 305 (1882).
315. Czapek, *Monatsh.*, **35**, 635 (1914); Lumière and Perrin, *Bull. soc. chim.*, [3] **29**, 1228 (1903).
316. Burkhardt, Lapworth, and Ashworth, *J. Chem. Soc.*, 684 (1926).
317. Hofmann and Biesalski, *Ber.*, **45**, 1394 (1912).
318. Verley, *Bull. soc. chim.*, [3] **25**, 46 (1901).
319. Durand and Hugenin, British pat., 202,630, *C.A.*, **18**, 333 (1924).
320*a*. Burkhardt, *J. Chem. Soc.*, 337 (1933). *b*. Burkhardt, Ford, and Singleton, *ibid.*, 17 (1936); Burkhardt, Evans, and Warhurst, *ibid.*, 25 (1936). *c*. Burkhardt, Horrex, and Jenkins, *ibid.*, 1649, 1654 (1936).
321. Kranzfelder and Sowa, *J. Am. Chem. Soc.*, **59**, 1490 (1937).
322. Heymann and Königs, *Ber.*, **19**, 704 (1886).
323. Burkhardt and Wood, *J. Chem. Soc.*, 141 (1929).
324. Hentrich, Hardtmann, and Ossenbeck, U. S. pat., 1,847,513, *C.A.*, **26**, 2469 (1932); Lange, German pat., 532,394, *C.A.*, **26**, 153 (1932).
325. Battegay and Denivelle, *Compt. rend.*, **194**, 1505 (1932); **195**, 1291 (1932).
326. Fairweather and Thomas, U. S. pat., 1,904,721, *C.A.*, **27**, 3482 (1933).
327. Ratti, U. S. pat., 1,999,477, *C.A.*, **29**, 4023 (1935).
328. Fairweather and Thomas, U. S. pats., 1,949,299, *C.A.*, **28**, 2725 (1934); 1,970,083, *C.A.*, **28**, 6322 (1934).
329. Barkenbus and Owen, *J. Am. Chem. Soc.*, **56**, 1204 (1934).
330. Levaillant, *Compt. rend.*, **200**, 940 (1935); *Ann. chim.*, **6**, 459 (1936).
331. Isham, U. S. pat., 1,744,227, *C.A.*, **24**, 1392 (1930); Brooks, U. S. pat., 2,081,166, *C.A.*, **31**, 4988 (1937); U. S. pats., 2,096,878 and 2,096,879, *C.A.*, **32**, 191 (1938); Lacy, U. S. pat., 2,009,062, *C.A.*, **29**, 5855 (1935); U. S. pat., 1,991,948, *C.A.*, **29**, 2174 (1935); Young, U. S. pat., 2,047,606, *C.A.*, **30**, 6010 (1936); Merley, U. S. pat., 1,998,411, *C.A.*, **29**, 3690 (1935). See also Krauze and Kogan, *Sintet. Kauchauk*, **3**, No. 5, 29 (1934); *C.A.*, **32**, 5774 (1938).
332. McKee, U. S. pat., 1,641,005, *C.A.*, **21**, 3369 (1927).
333. Dumas and Peligot, *Ann.*, **15**, 40 (1835); *J. prakt. Chem.*, **3**, 369 (1835).
334. Guyot and Simon, *Compt. rend.*, **169**, 655 (1919).
335. Levaillant and Simon, *Compt. rend.*, **169**, 140 (1919).
336. Blackler, *Chem. News*, **83**, 303 (1901).
337. Guyot and Simon, *Compt. rend.*, **169**, 655, 795 (1919).
338. Etablissements Lambiotte Frères, British pat., 336,681, *C.A.*, **25**, 1841 (1931).

339. Haworth and Irvine, British pat., 122,498, *C.A.*, **13**, 1716 (1919).
340. Durrans, U. S. pat., 1,317,648, *C.A.*, **14**, 70 (1920).
341. Levaillant and Simon, *Compt. rend.*, **169**, 854 (1919).
342. Dreyfus, British pat., 177,189, *C.A.*, **16**, 3094 (1922).
343. Levaillant, *Compt. rend.*, **187**, 234 (1928).
344. Kraft and Lyutina, *J. Gen. Chem.* (*U.S.S.R.*), **1**, 190 (1931); *C.A.*, **26**, **2167** (1932).
345. Levaillant, *Compt. rend.*, **189**, 465 (1929).
346. Guyot and Simon, *ibid.*, **168**, 1054 (1919).
347. Walden, *Z. physik. Chem.*, **54**, 131 (1906).
348. Lewis, Mason, and Morgan, *Ind. Eng. Chem.*, **16**, 811 (1924).
349. Olivier and Berger, *Rec. trav. chim.*, **41**, 637 (1922).
350. Pollak and Baar, *Monatsh.*, **38**, 501 (1918).
351. Kremann, *ibid.*, **27**, 1265 (1906).
352. Klemenc and Edhofer, *ibid.*, **38**, 553 (1918).
353. Mueller, *Chem. Met. Eng.*, **23**, 833 (1920).
354. Dumas and Peligot, *Ann. chim. phys.*, **58**, 32 (1835).
355. Claësson and Lundvall, *Ber.*, **13**, 1699 (1880).
356. Babo, *J. prakt. Chem.*, **72**, 84 (1857); *Chem. Zentr.*, 218 (1858).
357. Ullmann and Wenner, *Ber.*, **33**, 2476 (1900).
358. Werner, *J. Chem. Soc.*, **105**, 2762 (1914).
359. Shepard, *J. Am. Chem. Soc.*, **38**, 2507 (1916).
360*a*. Ullmann, *Ann.*, **327**, 104 (1903). *b*. J. R. Geigy A.-G., Swiss pats., 207,299-207,303, *C.A.*, **35**, 3010 (1941).
361. Bamberger, *Ber.*, **37**, 966 (1904).
362. Bamberger and Rudolf, *Ber.*, **39**, 4285 (1906).
363. See Johnson and Guest, *J. Am. Chem. Soc.*, **32**, 761 (1910), for references previous to their work.
364. Ullmann and Naef, *Ber.*, **33**, 2470 (1900); Ullmann and Marič, *Ber.*, **34**, 4307 (1901).
365. Decker, *Ber.*, **33**, 2276 (1900); **36**, 261 (1903); **38**, 1147, 2493 (1905); Decker and Schenk, *Ber.*, **39**, 748 (1904); Schmid and Decker, *Ber.*, **39**, 933 (1906).
366. Gadomska and Decker, *Ber.*, **36**, 2487 (1903).
367. Gibson and Vining, *J. Chem. Soc.*, **123**, 831 (1923).
368. Simon and Frèrejacques, *Compt. rend.*, **176**, 900 (1923).
369. Lewis, Shaffer, Trieschmann, and Cogan, *Ind. Eng. Chem.*, **22**, 34 (1930).
370. Ullmann, *Ann.*, **327**, 104 (1903).
371. Graebe, *Ann.*, **340**, 204 (1905).
372. See also *Org. Syntheses, Coll. Vol. 1,* John Wiley & Sons, New York (1932), pp. 50, 522.
373. Wolford, *Ind. Eng. Chem.*, **22**, 397 (1930).
374. Graebe and Martz, *Ann.*, **340**, 213 (1905); Graebe and Suter, *Ann.* **340**, 222 (1905); Graebe and Hess, *Ann.*, **340**, 232 (1905); Graebe, *Ber.*, **38**, 152 (1905); Kostanecki and Lampe, *Ber.*, **35**, 1669 (1902); **37**, 774 (1904); **41**, 1330 (1908); Bülow and Riess, *Ber.*, **35**, 3901 (1902); Meyer, *Ber.*, **40**, 2432 (1907); Decker and Koch, *Ber.*, **40**, 4794 (1907); Perkin and Robinson, *J. Chem. Soc.*, **91**, 1079 (1907); Tambor, *Ber.*, **43**, 1882 (1910); Calombano, *Atti accad. Lincei,* [2] **16**, 457 (1907); Slotta and Franke, *Ber.*, **64B**, 86 (1931).
375. Pauly, Schübel, and Lockemann, *Ann.*, **383**, 321 (1911).

376. Hodgson and Nixon, *J. Chem. Soc.*, 2166 (1930).

377. Shah, Bhatt, and Kanga, *J. Univ. Bombay*, **3**, 155 (1934); *C.A.*, **29**, **4747** (1935).

378. The following references give typical examples: Friedlander, *Ann.*, **351**, 401 (1907); Auwers and Arndt, *Ber.*, **42**, **540**, 2713 (1909); Brand, *Ber.*, **42**, 3463, 3988 (1909); Mayer, *Ber.*, **42**, 3046 (1909); Fricke and Spilker, *Ber.*, **58B**, 24 (1925); Pollak and Schadler, *Monatsh.*, **39**, 129 (1918); Suter and Hansen, *J. Am. Chem. Soc.*, **54**, 4100 (1932); Gilman and Beaber, *ibid.*, **47**, 1449 (1925).

379. Kehrmann and Duttenhöfer, *Ber.*, **39**, 3559 (1906).

380. Baeyer, *Ber.*, **43**, 2337 (1910).

381. Simon, *Compt. rend.*, **176**, 583 (1923).

382. Dumas and Peligot, *J. prakt. Chem.*, **3**, 369 (1835).

383. Werner, *Ann.*, **321**, 269 (1902); Werner and Seybold, *Ber.*, **37**, 3658 (1904); Meyer, *Ber.*, **37**, 4144 (1904); *Monatsh.*, **25**, 476 (1904); Wegscheider, *ibid.*, **23**, 383 (1902).

384. Archibald and Lebo, U. S. pat., 1,844.536, *C.A.*, **26**, 1945 (1932); Merley, U. S. pat., 1,924,616; Spring, U. S. pat., 1,924,575, and Merley and Spring, U. S. pat., 1,924,615, *C.A.*, **27**, 5338 (1933).

385. Werner, *Ann.*, **321**, 269 (1902).

386. Novák, *Ber.*, **45**, 834 (1912); Edlbacher, *Z. physiol. Chem.*, **110**, 153 (1920); **107**, 52 (1919); **108**, 287 (1919).

387. Simon and Frèrejacques, *Compt. rend.*, **177**, 533 (1923).

388*a*. Bühner, *Ann.*, **333**, 289 (1904); Matsui, *Mem. Coll. Sci. Eng. Kyoto*, **2**, 37 (1909); *C.A.*, **5**, 475 (1911). *b*. Thielepape and Fulde, *Ber.*, **68B**, 751 (1935).

389. Werner, *J. Chem. Soc.*, **105**, 923 (1914).

390. Kremann, *Monatsh.*, **27**, 1265 (1906).

391. Nef, *Ann.*, **309**, 186 (1899).

392. Guyot and Simon, *Compt. rend.*, **169**, 534 (1919).

393. Rabcewicz-Lubkowsky, *J. prakt. Chem.*, [2] **86**, 319 (1912); Cerchez, *Bull. soc. chim.*, **43**, 762 (1928).

394. Cope, *J. Am. Chem. Soc.*, **56**, 1342 (1934).

395. Swallen and Boord, *ibid.*, **52**, 653 (1930).

396. Haworth, *J. Chem. Soc.*, **107**, 8 (1915).

397. Haworth and Law, *ibid.*, **109**, 1314 (1916); Haworth and Leitch, *ibid.*, **115**, 809 (1919); **113**, 188 (1918); Haworth and Hirst, *ibid.*, **119**, 193 (1921).

398. Irvine and Montgomery, *J. Am. Chem. Soc.*, **55**, 1988 (1933).

399. Muskat, *ibid.*, **56**, 693 (1934).

400. Nef, *Ann.*, **309**, 186 (1899).

401. Grandmougin, Havas, and Guyot, *Chem.-Ztg.*, **37**, 812 (1913).

402. Bailly, *Compt. rend.*, **170**, 1061 (1920); *Bull. soc. chim.*, **27**, 744 (1920).

403. Dumas and Peligot, *J. prakt. Chem.*, **3**, 369 (1835).

404. Walden, *Ber.*, **40**, 3214 (1907).

405. Slotta and Lorenz, *Ber.*, **58B**, 1320 (1925).

406. Binz, *Ber.*, **37**, 3549 (1904).

407. Bunte, *Ber.*, **7**, 648 (1874).

408*a*. Guyot and Simon, *Compt. rend.*, **169**, 435 (1919). *b*. Shamshurin, *C.A.*, **34**, 4052 (1940).

409. Boulin and Simon, *Compt. rend.*, **170**, 595 (1920).

410. Boulin and Simon, *ibid.*, **169**, 619 (1919).

411. Guyot and Simon, *ibid.*, **168**, 1204 (1919).

412. Hartley, *J. Chem. Soc.*, **97**, 1067, 1725 (1910).

413. Marvel, Helfrich, and Belsly, *J. Am. Chem. Soc.*, **51**, 1272 (1929).

414. Levaillant, *Compt. rend.*, **200**, 1053 (1935).

415. Levaillant and Simon, *ibid.*, **169**, 234 (1919); Boulin and Simon, *ibid.*, **169**, 338 (1919).

416. Schlenk and Schlenk, *Ber.*, **62B**, 920 (1929); Schlenk, Jr., *Ber.*, **64B**, 734 (1931).

417. Werner and Zilkins, *Ber.*, **36**, 2116 (1903).

418. Houben, *Ber.*, **36**, 3085 (1903).

419. Suter and Gerhart, *J. Am. Chem. Soc.*, **57**, 107 (1935).

420. Smith and MacDougall, *ibid.*, **51**, 3001 (1929).

421. Veselý and Štursa, *Collection Czechoslov. Chem. Commun.*, **6**, 137 (1934); *C.A.*, 28, 5815 (1934).

422. Cope, *J. Am. Chem. Soc.*, **56**, 1578 (1934).

423. Houben, *Ber.*, **37**, 488 (1904).

424. Ferrario and Fagetti, *Gazz. chim. ital.*, **38**, II, 630 (1908).

425. Whitmore and Fleming, *J. Am. Chem. Soc.*, **55**, 3803 (1933).

426. Houben, *Ber.*, **37**, 488 (1904).

427*a*. Thorn, Hennion, and Nieuwland, *J. Am. Chem. Soc.*, **58**, 796 (1936). *b*. Gilman and Young, *ibid.*, **57**, 1121 (1935). *c*. Belov and Lebedev, *C.A.*, **35**, 2879 (1941).

428*a*. Kane and Lowy, *J. Am. Chem. Soc.*, **58**, 2605 (1936); Shamshurin, *C.A.*, **35**, 3981 (1941). *b*. Epelberg and Lowy, *C.A.*, **63**, 101 (1941).

429. Houben and Arnold, *Ber.*, 40, 4306 (1907); Jones and Whalen, *J. Am. Chem. Soc.*, 47, 1351 (1925).

430*a*. Volmar and Dufraise, *Bull. soc. chim.*, **27**, 680 (1920). *b*. Wood, *J. Soc. Chem. Ind.*, **50**, 411T (1931).

431. Houben and Arnold, *Ber.*, **41**, 1565 (1908).

432. Houben and Arnold, *Ber.*, 40, 4306 (1907).

433. Fuchs and Katscher, *Ber.*, **60B**, 2288 (1927); British pat., 299,064, *C.A.*, **23**, 2990 (1929).

434. Grignard, Toussaint, and Cazin, *Bull. soc. chim.*, **43**, 537 (1928).

435. Wetherill, *Ann.*, **66**, 117 (1848).

436*a*. Nef, *Ann.*, **318**, 10 (1901). *b*. Bushong, *Am. Chem. J.*, **30**, 212 (1903).

437. Villiers, *Compt. rend.*, **90**, 1291 (1880).

438. Kuh, British pat., 149,688, *C.A.*, **15**, 374 (1921); Lynn and Shoemaker, *J. Am. Chem. Soc.*, **46**, 999 (1924).

439. Dreyfus, British pat., 177,189, *C.A.*, **16**, 3094 (1922).

440. Köhler, *Ber.*, **11**, 1926 (1878).

441. Plant and Sidgwick, *J. Soc. Chem. Ind.*, 40, 14 (1921); British pat., 157,578, *C.A.*, **15**, 1905 (1921); N. V. de Bataafsche Petroleum Maatschappij, French pat., 718,943, *C.A.*, **26**, 3261 (1932); Damiens, *Compt. rend.*, **175**, 585 (1922); *Bull. soc. chim.*, **33**, 71 (1923).

442. Curme and Curme, *Chem. & Met. Eng.*, **25**, 957 (1921); Curme, U. S. pat., 1,339,947, *C.A.*, **14**, 2001 (1920).

443. Maimeri, *C.A.*, **19**, 1402 (1925); Brooks, U. S. pat., 1,885,585, *C.A.*, **27**, 1011 (1933).

444. Carruthers, U. S. pat., 1,949,366, *C.A.*, **28**, 2731 (1934); Cox, U. S. pat., 1,949,369, *C.A.*, **28**, 2731 (1934).

445. Lilienfeld, U. S. pat., 1,427,215, *C.A.*, **16**, 3665 (1922).

446*a*. Levaillant, *Compt. rend.*, **190**, 54 (1930). *b*. *Ibid.*, **189**, 465 (1929).

447. Gerhart, this laboratory, unpublished results.

448. Levaillant, *Compt. rend.*, **196**, 882 (1932).

449. Cade, *Chem. & Met. Eng.*, **29**, 319 (1923).

450. Kremann, *Monatsh.*, **27**, 1265 (1906).

451. Teupel, German pat., 574,833, *C.A.*, **27**, 4543 (1933).

452. Gilman and Hoyle, *J. Am. Chem. Soc.*, **44**, 2625 (1922); Gilman and Beaber, *ibid.*, **47**, 520 (1925); Evans and Gerhart, this laboratory, unpublished results.

453. Baeyer and Villiger, *Ber.*, **33**, 3387 (1900).

454. Engelhardt and Lommel, German pat., 507,961, *C.A.*, **25**, 710 (1931).

455. Gilman and Fothergill, *J. Am. Chem. Soc.*, **50**, 802 (1928).

456. Nekrasov and Komisarov, *J. prakt. Chem.*, **123**, 160 (1929).

457. Levaillant, *Compt. rend.*, **187**, 730 (1928).

458. Suter and Evans, *J. Am. Chem. Soc.*, **60**, 536 (1938); Evans, Ph.D. thesis, Northwestern University, 1935.

459. Chem. Fabr. vorm. Weiler-Ter Meer, German pat., 374,141, *C.A.*, **18**, 2176 (1924).

460. Nef, *Ann.*, **318**, 40 (1901).

461. Medvedev and Alekseeva, *Ber.*, **65B**, 131 (1932).

462. Levaillant, *Compt. rend.*, **188**, 261 (1929).

463. Levaillant, *ibid.*, **197**, 648 (1933).

464. Levaillant, *ibid.*, **197**, 335 (1933).

465*a*. Plant and Sidgwick, *J. Soc. Chem. Ind.*, **40**, 14T (1921). *b*. Ormandy and Craven, *ibid.*, **49**, 362T (1930). *c*. See also Davies, U. S. pat., 1,966,166, *C.A.*, **28**, 5468 (1934). *d*. N. V. de Bataafsche Petroleum Maatschappij, French pat., 718,943, *C.A.*, **26**, 3261 (1932). *e*. Khain and Nazarov, *C.A.*, **31**, 6188 (1937). *f*. Katuno, *C.A.*, **34**, 6929 (1940).

466. Bert, *Bull. soc. chim.*, **37**, 1252 (1925).

467. Gerhart, Ph.D. thesis, Northwestern University, 1935.

468. Schlenk and Schlenk, *Ber.*, **62B**, 920 (1929); Schlenk, Jr., *Ber.*, **64B**, 734 (1931).

469. Engs and Moravec, U. S. pat., 1,854,581, *C.A.*, **26**, 3265 (1932); French pat., 718,943.

470. N. V. de Bataafsche Petroleum Maatschappij, German pat., 577,947, *C.A.*, **28**, 489 (1934).

471. Chapman, *Chem. News*, **22**, 237 (1870).

472. Heusler, *Ber.*, **28**, 498 (1895).

473. Behrend, *Ber.*, **9**, 1334 (1876).

474. Bert, *Compt. rend.*, **178**, 1182 (1924).

475. Thayer, *J. Am. Chem. Soc.*, **46**, 1044 (1926).

476. Lacy, U. S. pat., 2,009,062, *C.A.*, **29**, 5855 (1935).

477. v. Braun and Müller, *Ber.*, **50**, 293 (1917).

478. Gomberg and Cone, *Ber.*, **37**, 3543 (1904); **40**, 1849 (1907).

479. Delépine, *Compt. rend.*, **129**, 831 (1899); *Bull. soc. chim.*, **21**, 1055 (1899).

480. Baker, *J. Chem. Soc.*, 1765 (1931).

481. Fuchs and Katscher, *Ber.*, **60B**, 2288 (1927).

482. Baker and Field, *J. Chem. Soc.* 86 (1932).
483. Delaby, *Bull. soc. chim.*, **39**, 1612 (1926).
484. Wood, *J. Soc. Chem. Ind.*, **50**, 411T (1931).
485. Ruggli and Henzi, *Helv. Chim. Acta*, **12**, 364 (1929); Perkins, U. S. pat., 1,999,995, *C.A.*, **29**, 4026 (1935).
486. Fischer and Taube, *Ber.*, **59B**, 851 (1926).
487. Denivelle, *Compt. rend.*, **199**, 211 (1934).
488. J. R. Geigy A.-G., Swiss pats., 167,028 to 167,031, *C.A.*, **28**, 5698 (1934).

CHAPTER II

ALIPHATIC SULFONIC ACIDS

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Although the practical importance of the simple aliphatic sulfonic acids is at present comparatively small, considerable information concerning them is available, and some of their derivatives have commercial value. The compounds which have received the most attention are either the derivatives of methane and ethane or of the carboxylic acids. Fatty acid esters of 2-hydroxyethane-1-sulfonic acid (isethionic acid) and amides derived from 2-aminoethane-1-sulfonic acid (taurine) have found application as detergents and wetting agents. Sulfonic acids are present to some extent in the "sulfonated oils" used for various purposes in the textile industry. The structures of the sulfonation products of this type are largely unknown and this field offers interesting possibilities for research. Most of the information so far available is of an empirical nature, and it is difficult to distinguish between fact and hope in the voluminous patent literature on the subject.

ALKANESULFONIC ACIDS

General Methods of Preparation. Direct sulfonation of the aliphatic hydrocarbons has been of only occasional value in preparing the sulfonic acids.

It has been noted that methane,[1] ethane,[1] and propane[2] dissolve slowly in fuming sulfuric acid, but the compounds formed have apparently not been isolated. Isobutane[3] dissolves readily with the formation of a compound which is probably not the 2-methylpropane-2-sulfonic acid because of its low solubility in water. *n*-Hexane, *n*-heptane, and *n*-octane[4] react with fuming sulfuric acid to give compounds which analyze for the monosulfonic acids; sulfur trioxide, at the boiling point of the hydrocarbon, gives disulfonated products. A more recent[5] investigation indicates that these latter compounds, at least, may have been esters of hydroxysulfonic acids rather than disulfonic acids. Apparently oxidation occurs very readily, particularly with sulfonated compounds, and the resulting unsaturated derivatives add sulfuric acid to give esters. This may be illustrated as follows.

$$CH_3(CH_2)_4CH_3 + SO_3 \rightarrow CH_3(CH_2)_3CH(SO_3H)CH_3$$

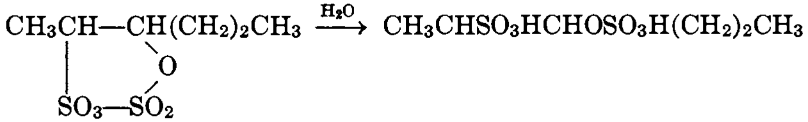
$$CH_3(CH_2)_3CH(SO_3H)CH_3 + SO_3 \rightarrow CH_3CH_2CH_2CH{=}C(SO_3H)CH_3 + H_2O + SO_2$$

$$CH_3CH_2CH_2CH{=}C(SO_3H)CH_3 + H_2SO_4 \rightarrow CH_3CH_2CH_2CH(OSO_3H)CH(SO_3H)CH_3$$

An alternative explanation would be to assume the oxidation of the hydrocarbon to an olefin as the first step. Addition of sulfur trioxide to this would give the sulfate sulfonate.

$$CH_3(CH_2)_4CH_3 + SO_3 \rightarrow CH_3CH{=}CH(CH_2)_2CH_3 + SO_2 + H_2O$$

$$CH_3CH{=}CH(CH_2)_2CH_3 + 2SO_3 \rightarrow$$



$$\underset{\displaystyle SO_3\!-\!SO_2}{CH_3CH\!-\!CH(CH_2)_2CH_3}\ (\text{ring closed through } O) \xrightarrow{H_2O} CH_3CHSO_3HCHOSO_3H(CH_2)_2CH_3$$

Cyclohexane[5,6,7] is even more readily oxidized by fuming sulfuric acid, and the products, aside from benzenesulfonic acid, are apparently hydrogen sulfates of hydroxycyclohexanesulfonic acids of unknown structures. Methylcyclohexane behaves similarly. The reaction of 35 or 65% oleum with these compounds occurs readily at 0–10°, indicating a greater reactivity than is usually credited to saturated hydrocarbons.

The higher paraffin hydrocarbons[8] undergo oxidation with sulfuric acid but no sulfonic acids have been isolated. Chlorosulfonic acid reacts readily with branched-chain hydrocarbons[9] such as isopentane and 2,4-dimethylbutane (diisopropyl) but quite slowly with *n*-hexane.[10a] This difference in reactivity has been utilized[10b] in preparing pure straight-chain hydrocarbons from petroleum. Although sulfonic acids were noted in some instances, none has apparently been separated in a pure state and identified. It may be concluded that, in general, direct sulfonation gives at best only small yields of compounds whose structures are so far uncertain. The chief complication is oxidation which may occur either before or after substitution takes place. The photochemical sulfonation of hydrocarbons with sulfur dioxide and chlorine[11a] followed by hydrolysis of the sulfonyl chlorides to the sulfonic acids has been described in the patent literature. Treating *n*-heptane with sulfuryl chloride in the presence of pyridine or quinoline produces sulfonyl chlorides as well as chlorination products.[11b]

The addition of bisulfites to olefins takes place slowly in cold dilute solution.[12] The presence of an oxidizing agent such as oxygen or a nitrite is essential, which has led to the suggestion that the reaction can best be interpreted upon the basis of a free radical mechanism,[12d] since a bisulfite may be converted into a free radical or free radical ion by an oxidizing agent. The rate of addition is greatly affected by the hydrogen-ion concentration. Ethylene does not react with ammonium bisulfite at *p*H 4.8 while at 5.9 the reaction proceeds at an appreciable rate. With propylene the maximum rate of addition occurred in the range of *p*H 5.1 to 6.1. Addition of bisulfite to isobutylene, trimethylethylene, cyclohexene, pinene, dipentene, and styrene has also been noted. Where the structures of the products have been determined addition does not occur according to Markownikoff's rule. Propylene gives the propane-1-sulfonate, isobutylene the 2-methylpropane-1-sulfonate, and styrene the 1-phenylethane-2-sulfonate.[12d,f] In this last instance the chief product of the reaction is 1-phenyl-1-hydroxyethane-2-sulfonic acid; some 1-phenylethylene-2-sulfonic acid also is formed when oxygen is present but not in the presence of other oxidizing agents.[12f]

The yields of sulfonates obtained from olefins and a bisulfite are, in general, not high. The best results were those obtained by Kharasch[12d] with isobutylene and sodium bisulfite, where a 62% yield of crude product was isolated. With ethylene 12% of barium ethanesulfonate was formed in the reaction of excess ethylene and oxygen upon 2 *N* ammonium sulfite solution. No addition whatever occurred in the absence of an oxidizing agent.

Thiols react vigorously with concentrated nitric acid to give as final products the corresponding sulfonic acids. A considerable number has been made in this way, including the ethane-,[13] propane-1-,[14] propane-2-,[15] butane-1-,[16] *d*-butane-2-,[17] 2-methylpropane-1-,[14,18] pentane-2-,[19] 3-methylbutane-1-,[20] hexane-1-,[19,21] hexane-2-,[19] 2-methylpentane-2-,[22a] and octane-2-sulfonic [22b] acids. Others are mentioned in the patent literature.[23] With one exception [16b] no yields were recorded for these reactions. It has been found [24] that oxidation of the lead salts of the thiols with nitric acid gives better yields than are obtained from the thiols themselves. For the series of normal chain acids containing from nine to fourteen carbon atoms the yield of lead sulfonate is usually above 60% of the theoretical amount. The lead sulfonates are easily convertible into the free acids by treatment with hydrogen chloride in isopropyl alcohol.

$$(RS)_2Pb + 12HNO_3 \rightarrow (RSO_3)_2Pb + 12NO_2 + 6H_2O$$

$$(RSO_3)_2Pb + 2HCl \rightarrow 2RSO_3H + PbCl_2$$

By the oxidation of a mixture of hexadecanethiol-1 and the disulfide with fuming nitric acid [25] the sulfonic acid is obtained in 98% yield, which is contrary to the observation of Reychler [26] that this thiol reacted explosively with nitric acid and hence another oxidizing agent was preferable. The yields obtained in this type of oxidation reaction undoubtedly depend on how much excess nitric acid is used, as dilute acid remaining at the end of the reaction might not oxidize the intermediate disulfide and disulfoxide completely to the sulfonic acid. It is also probable that disulfides can be used in place of the thiols, as these would be formed as the first stage in the oxidation process. Oxidation of ethyl disulfide to the sulfonic acid by the action of 50% nitric acid has been described.[27]

It has been found [22,26,28] that the higher alkanesulfonic acids can be made in good yields by oxidation of the corresponding thiols or disulfides in acetone or acetic acid solution with potassium permanganate or dichromate. The acids are precipitated from solution by concentrated hydrochloric acid. Potassium permanganate had previously been employed in the oxidation of ethanethiol to the sulfonic acid.[29]

Recently [30] it has been shown that hydrogen peroxide oxidizes dimethylethylmethanethiol to the sulfonic acid.

The oxidation method of preparation has been of value in determining the relative influence of thiol and sulfo groups upon the optical rotation caused by an asymmetric carbon atom, as there is no possibility of a Walden inversion during the reaction.[28]

Oxidation of several alkyl thiocyanates with nitric acid[81] has resulted in good yields[82] of the sulfonic acids. As the thiocyanates are readily obtainable, this method deserves more attention than it has received. With concentrated acid the reaction is violent, and an appreciable quantity of sulfuric acid is formed. As other products, carbon dioxide and oxides of nitrogen are evolved.

$$CH_3SCN + 13HNO_3 \rightarrow CH_3SO_3H + CO_2 + 14NO_2 + 6H_2O$$

$$CH_3SCN + 21HNO_3 \rightarrow H_2SO_4 + 2CO_2 + 22NO_2 + 11H_2O$$

Oxidation of methyl, ethyl, *n*-amyl, and methylene thiocyanates with bleaching powder solution[83] gives the sulfonic acids with evolution of nitrogen and carbon dioxide. Good yields of methane- and ethanesulfonic acids are likewise obtained[84] by electrolytic oxidation of the thiocyanates in 50% acetic acid to which hydrochloric acid has been added. Chlorine water oxidation of *n*-heptyl sulfoxide gives a small yield of the heptanesulfonic acid.[85a] More recently it has been shown that the action of chlorine on an aqueous solution of an alkylation product of thiourea gives a sulfonyl chloride in many instances.[85b,c,f] The yields are good for primary alkyl groups but are low for *sec*-alkyls and zero for the *tert*-butyl compound and other miscellaneous isothiourea derivatives.

$$RSC(NH_2){=}NH + 3Cl_2 + 2H_2O \rightarrow RSO_2Cl + 4HCl + [ClC(NH_2)NH]$$

(On a few occasions dangerous explosions have occurred when the reaction mixture was being processed. These may result from the formation of nitrogen trichloride but further investigation will be necessary to establish this.) Bromine acts in similar fashion. Sulfonic acids or their salts are readily obtained by hydrolysis of the sulfonyl halides. The action of chlorine upon an aqueous suspension of an alkyl thiocyanate[85c,e,g] and upon a variety of other compounds containing an S-alkyl group[85d,h] likewise yields the sulfonyl halides.

$$RSCN + 3Cl_2 + 2H_2O \rightarrow RSO_2Cl + 4HCl + ClCN(?)$$

The reaction of an alkyl halide with an alkali sulfite in aqueous solution forms a sulfonic acid[86,87] rather than an oxygen ester of sulfurous acid. By substituting ammonium sulfite[88] for the alkali salt the resulting sulfonate becomes more easily convertible into other salts of the acid, and apparently the formation of a stable double salt of ammonium iodide and ammonium sulfonate does not occur as it does with the alkali metal salts. The 90% yields of ammonium sulfonates reported by Hemilian[88] for this method have not been verified,[19,88b] but it is possible to replace the alkyl iodides with the cheaper bromides or chlorides and obtain yields ranging from 50 to 90% of the theoretical amounts. It was reported by several investigators [28a,b] that the high-molecular-weight sulfonic acids could not be prepared by the action of the bromides with a sulfite but it was later [37b,39a] found that by heating *n*-octyl, *n*-decyl, myristyl, cetyl, or octadecyl bromide, or lauryl chloride with an excess of aqueous sodium sulfite in an autoclave at 200° for several hours a 60–70% yield of the sulfonate results. Cyclopentylalkyl chlorides have been converted into sulfonates in this way also.[39b] This reaction eliminates one step necessary in the preparation of the sulfonic acids from the bromides through the thiols and avoids handling these latter substances.[40]

Another method of proceeding from an alkyl halide to a sulfonic acid involves the intermediate formation of the sulfinic acid from the Grignard reagent and its subsequent oxidation. In this manner methane- and ethanesulfonic acids [41] have been obtained by oxidation of the sulfinic acids with bromine water, and cyclopentane-, cyclohexane-, and 3-methylcyclohexanesulfonic acids by oxidation with potassium permanganate.[42]

Methods for synthesizing sulfonic acids applied in only one or two cases are mentioned under a discussion of the compounds concerned.

Properties and Reactions. The common physical properties [16b] of the first six members of the series of alkanesulfonic acids are listed in Table I. The alternations of the melting point and the high densities of the first members of the series are apparent. The phenylhydrazine salts of the first eight members of the series have been shown to be suitable as derivatives.[43] They have convenient melting points (listed in Table I) and may be titrated with standard alkali for quantitative estimation. The amides derived from 2-naphthylamine are also characteristic for some of the lower acids.[37a] The melting points

TABLE I

Compound	B.P., °C. (mm.)	M.P., °C.	M.P. $C_6H_5NHNH_2$ Salt, °C.	d_4^{25}
CH_3SO_3H	167 (10)	+20	193.5–194	1.4844
$C_2H_5SO_3H$	....	−17	182.8	1.3341
n-$C_3H_7SO_3H$	136.(1)	+ 7.5	204.5	1.2516
n-$C_4H_9SO_3H$	147 (0.5)	−15.2	114–115	1.1906
n-$C_5H_{11}SO_3H$	163 (1)	+15.9	108–108.2	1.1226
n-$C_6H_{13}SO_3H$	174 (1)	+16.1	101–101.6	1.1047

for members of the series containing from nine to fourteen carbon atoms have been determined.[44a] The melting points of the acids and their benzylaniline salts are listed in Table II. These salts have been suggested as suitable for identification purposes.

TABLE II

BENZYLANILINE SALTS OF ALKANESULFONIC ACIDS

Sulfonic Acid	M.P., °C.	Benzylaniline Salts, M.P., °C.
$CH_3(CH_2)_8SO_3H$	46	90.5–91
$CH_3(CH_2)_9SO_3H$	46.5	84.0–84.5
$CH_3(CH_2)_{10}SO_3H$	49	84.6–84.7
$CH_3(CH_2)_{11}SO_3H$	52	91.0–91.2
$CH_3(CH_2)_{12}SO_3H$	58	87.5–88.0
$CH_3(CH_2)_{13}SO_3H$	65.5	82.5–82.7
$CH_3(CH_2)_{15}SO_3H$	53–54	....

Levene and associates[44b] have reported on the rotatory dispersion of some optically active sulfonic acids. This investigation was made difficult by the position of the absorption band in the far ultraviolet.

The reactions of aliphatic sulfonic acids are somewhat similar to those of the more thoroughly studied aromatic compounds. Thus, boiling dilute sodium hydroxide is without effect, but heating in 5% sodium hydroxide above 300° under pressure results in slow decomposition.[19] The extent to which various sulfonic acids decompose when a

$$RSO_3Na + NaOH \rightarrow ROH + Na_2SO_3$$

solution 0.5 *M* in the sodium sulfonate and 2 *M* in sodium hydroxide is heated at 345° for 3 hours is shown in Table III. At this temperature the alcohol is not recovered, but in the case of primary alcohols is further oxidized to the acid. The products resulting from the sec-

$$RCH_2OH + NaOH \rightarrow RCOONa + 2H_2$$

ondary alcohols have not been determined. The extent of sodium sulfate formation in the reaction is negligible.

The reaction occurring between phosphorus halides and aliphatic sulfonic acids depends upon the halogen;[45] with phosphorus pentachloride or bromide the sulfonyl halide results whereas if phosphorus tribromide is also present the sulfonyl bromide is generally reduced to

TABLE III

SODIUM ALKANESULFONATES AND 2*M* ALKALI AT 345°

Sulfonic Acid	Decomposition, %	Sulfonic Acid	Decomposition, %
CH_3SO_3H	1.5	$C_6H_5CH_2SO_3H$	5.0
$CH_3CH_2SO_3H$	62.7	$(CH_3)_2CHSO_3H$	88.6
$CH_3(CH_2)_2SO_3H$	20.2	$CH_3CH(SO_3H)C_2H_5$	75.2
$CH_3(CH_2)_3SO_3H$	17.3	$CH_3CH(SO_3H)C_3H_7$	64.2
$CH_3(CH_2)_4SO_3H$	13.3	$CH_3CH(SO_3H)C_4H_9$	54.9
$CH_3(CH_2)_5SO_3H$	11.7	$C_6H_5SO_3H$	5.0

the disulfide unless the sulfonic acid is adjacent to a benzene ring as in toluene-ω-sulfonic acid. Here the sulfonic acid group is replaced by bromine.

$$RSO_3H + PBr_5 \rightarrow RSO_2Br + KBr + POBr_3$$

$$PBr_5 \rightleftharpoons PBr_3 + Br_2$$

$$2RSO_2Br + 5PBr_3 \rightarrow R\text{—}S\text{—}S\text{—}R + 4POBr_3 + PBr_5$$

$$C_6H_5CH_2SO_2Br + PBr_5 \rightarrow C_6H_5CH_2Br + [SOBr_2] + POBr_3$$

Aliphatic sulfonyl bromides result in some instances from the reaction of alkylmagnesium bromides with sulfuryl chloride.[46] If alkylmagnesium iodides or chlorides are used, however, the products are the sulfonyl chlorides[47] together with the sulfinic acids.

Aliphatic sulfonyl fluorides[48] have been prepared only by action of the sulfonyl chlorides upon zinc fluoride or potassium fluoride. Possibly antimony pentafluoride would react with sodium sulfonates to give fluorides. The phosphorus fluorides are probably too inert.

$$RSO_2Cl + KF \rightarrow RSO_2F + KCl$$

In Table IV are tabulated some of the properties of the sulfonyl chlorides, amides, and anilides derived from the lower-molecular-weight sulfonic acids.

The aliphatic sulfonic acids are inert toward the action of chlorine under ordinary conditions. Ethane and propane-1-sulfonic acids[49] do not react under any conditions so far investigated while 3-methylbutane-1-sulfonic[50] acid reacts only in the presence of light. A compound $C_5H_{10}ClSO_3H$, isoamyl chloride, and chlorosulfonic acid are the chief products. Heptane-1-sulfonic acid[51] gives a dichloro- and a trichloroheptane-1-sulfonic acid under similar conditions.

TABLE IV

DERIVATIVES OF ALKANESULFONIC ACIDS

Sulfonic Acid	B.P. of Chloride, °C. (mm.)	M.P. of Amide, °C.	M.P. of Anilide, °C.
CH_3SO_3H	161 (730)	90	100.5
$C_2H_5SO_3H$	177.5 (760)	58	58
$CH_3(CH_2)_2SO_3H$	77–78 (13)	52	10
$(CH_3)_2CHSO_3H$	79 (18)	60	84
$CH_3(CH_2)_3SO_3H$	96–97 (18)	45	10–15
$(CH_3)_2CHCH_2SO_3H$	80 (13)	14–16	38
$(CH_3)_2CH(CH_2)_2SO_3H$	98 (13)	3	42

By heating the sulfonic acids with iodine trichloride various complex changes can be brought about. Ethanesulfonic[49] acid at 150° with excess reagent for 7 hours reacts approximately as follows.

$$C_2H_5SO_3H + 4ICl_3 \rightarrow C_2Cl_6 + ClSO_3H + 5HCl + 2I_2$$

With a smaller amount of iodine trichloride a dichloroethanesulfonic acid results which probably has one chlorine on each carbon atom; with barium hydroxide only one of the chlorines was easily removed. Likewise with ammonia one of the chlorines was replaced by an amino group, and the silver salt upon heating in aqueous solution decomposed as follows.

$$C_2H_3Cl_2SO_3Ag + H_2O \rightarrow C_2H_3(OH)ClSO_3H + AgCl$$

Propane-1-sulfonic acid[49] with iodine trichloride yields a monochloro compound in which the chlorine is attached to the same carbon atom as the sulfo group since further reaction gives 1,1,1-trichloropropane and chlorosulfonic acid. These changes may be formulated as follows.

$$CH_3CH_2CH_2SO_3H \xrightarrow{ICl_3} CH_3CH_2CHClSO_3H \xrightarrow{ICl_3} CH_3CH_2CCl_3 + ClSO_3H$$

The monochloro compound forms a double acid with the unsubstituted acid of the composition $(C_3H_7SO_3H)_3 \cdot C_3H_6ClSO_3H$. 3-Methylbutane-1-sulfonic acid[50] with iodine trichloride behaves similarly to the acids already mentioned, the results indicating that chlorination occurs on the carbon atom attached to the sulfo group. The reaction is more vigorous in sunlight than in the dark.

This enhanced reactivity of the hydrogen adjacent to the sulfonic acid part of the molecule is also evidenced in the behavior of ethanesulfonic acid and toluene-ω-sulfonic acid toward hydrogen peroxide[52] in the presence of ferrous sulfate which converts these acids into acetaldehyde and benzaldehyde respectively.

METHANE- AND ETHANESULFONIC ACIDS

Methanesulfonic Acid and Its Derivatives. Methanesulfonic acid has been obtained in several ways not included among the methods of preparation already discussed. The reduction of trichloromethanesulfonic acid[53] either electrolytically or by the action of sodium amalgam or zinc occurs readily without the evolution of more than a trace of hydrogen until the reaction is nearly complete.

Shaking methyl iodide with ethyl sulfite and dilute potassium hydroxide[54] forms potassium methanesulfonate, probably through the hydrolysis of the ethyl sulfite[15a] to potassium sulfite followed by alkylation of this. Various other alkali salts have been obtained[55] by action of the proper metal sulfite upon methyl iodide.

Methyl sulfate reacts readily with aqueous potassium sulfite at 80–90° to give the sulfonate.[56] This was not isolated as such but was

$$(CH_3)_2SO_4 + K_2SO_3 \rightarrow CH_3SO_3K + KCH_3SO_4$$

converted into the sulfonyl chloride by treatment with phosphorus pentachloride. The yield of methanesulfonyl chloride was only 21–27% of the potassium sulfite used. This method of preparation suffers from the difficulty of separating potassium methyl sulfate and potassium methanesulfonate if the sulfonate is desired. The yield of sulfonate would probably be increased by substitution of sodium sulfite for the potassium compound.

Methanesulfonic acid has been obtained in small amounts from the oxidation of proteins[57] and from the action of fuming nitric acid at 200° upon γ-aminopropyl methyl sulfone.[58] This last reaction indicates the great stability of the acid toward oxidizing agents in an acidic solution.

When anhydrous, methanesulfonic acid melts at 20° and distils at 167° (10 mm.).[59] With water it forms both a mono- and a trihydrate. As indicated by its boiling point it is an "associated" liquid. When fused with potassium hydroxide[60] hydrogen is evolved and potassium carbonate and sulfite are present in the fusion mixture.

By electrolytic oxidation[61] at a platinum anode in aqueous solution, potassium methanesulfonate is converted into carbon dioxide, potassium sulfate, potassium persulfate, and a substance which upon acidifying the solution and boiling liberates formaldehyde. The nature of this compound was not determined.

By heating silver methanesulfonate with methanesulfonyl chloride[59a] at 160° the anhydride is produced.

$$CH_3SO_3Ag + CH_3SO_2Cl \rightarrow (CH_3SO_2)_2O + AgCl$$

The anhydride is also formed by the action of silver cyanate upon methanesulfonyl chloride.[59a] It crystallizes from ether in prisms, m.p. 71°, and distils at 138° (10 mm.). Hot water hydrolyzes it readily to the acid and with alcohol the ester is formed. This appears to be the only simple aliphatic sulfonic acid anhydride known.

$$(CH_3SO_2)_2O + C_2H_5OH \rightarrow CH_3SO_2OC_2H_5 + CH_3SO_3H$$

The usual method of obtaining methanesulfonyl chloride is by the action of phosphorus pentachloride upon a salt of the acid.[56, 59a, 62a] More recently the action of chlorine upon S-methylthiourea salts or methyl thiocyanate has been found to give good results.[35b, f]

$$CH_3SO_3Na + PCl_5 \rightarrow CH_3SO_2Cl + POCl_3 + NaCl$$

It has also been obtained by the action of chlorosulfonic acid[62b] on methanesulfonamide at 100°.

$$CH_3SO_2NH_2 + ClSO_3H \rightarrow CH_3SO_2Cl + NH_2SO_3H$$

It is a heavy ($d_4^{18°}$ 1.4805) water-insoluble liquid which may be distilled at atmospheric pressure without decomposition. It is readily hydrolyzed by hot water. In heating to 200° with sulfuryl chloride or with iodine trichloride no appreciable reaction was observed.[63] Silver cyanate gives in addition to the anhydride already mentioned a 5% yield of methanesulfonyl isocyanate.[59a] This compound reacts violently with water or alcohol to give the sulfonamide. What the second product is in the case of the alcohol reaction is not clear.

$$CH_3SO_2NCO + H_2O \rightarrow CH_3SO_2NH_2 + CO_2$$

An addition compound of methanesulfonyl chloride and aluminum chloride[64] evolves methyl chloride when heated alone, whereas in benzene, methyl phenyl sulfone results.

$$CH_3SO_2Cl \cdot AlCl_3 + C_6H_6 \rightarrow CH_3SO_2C_6H_5 + AlCl_3 + HCl$$

Heating with dry zinc fluoride at 160–170° gives an 80% yield of methanesulfonyl fluoride,[48] b.p. 124.2 (754 mm.), n_D^{20} 1.3596, characterized by a chloroform-like odor. Hydrolysis of the fluoride with boiling water is extremely slow, but with alkali the reaction is rapid.

Methanesulfonyl chloride reacts readily with alcoholic ammonia[65] to form methanesulfonamide. The amide undergoes an interesting reaction with aromatic diazonium salts.[66a]

$$CH_3SO_2NH_2 + 2C_6H_5N_2Cl \rightarrow CH_3SO_2N{=}N{-}C_6H_5 + C_6H_5N_3 + 2HCl$$

The reaction of methanesulfonyl chloride with aromatic amines[56] is conveniently carried out in benzene solution; the methanesulfonamides may serve as derivatives for the identification of the amines. These amides are somewhat more readily hydrolyzed than those derived from

$$CH_3SO_2Cl + 2RNH_2 \rightarrow CH_3SO_2NHR + RNH_3Cl$$

benzenesulfonyl chloride. The amides from primary amines were found to be soluble in 10% sodium hydroxide solution. Their melting points are given in Table V. The methanesulfonamides of certain amino acids and peptides have also been described.[66b]

TABLE V

METHANESULFONAMIDES

Amine	M.P., °C.	Amine	M.P., °C.
Aniline	100.5	2,5-Dichloroaniline	174
o-Toluidine	103	α-Naphthylamine	125.5
p-Toluidine	102.5	β-Naphthylamine	153.5
o-Anisidine	115.5	δ-Phenoxybutylamine	79.5
p-Anisidine	116	Methylaniline	76.5
p-Phenetidine	125	Ethylaniline	59
o-Chloroaniline	90.5	*n*-Propylaniline	76
p-Chloroaniline	148	*n*-Butylaniline	73
p-Bromoaniline	136	Benzylaniline	122

Methyl methanesulfonate results from the action of methyl iodide upon methyl sulfite[54] at 115°. It distils at 202.7–203° (748 mm.) and has the d_0^0 of 1.3206. The ethyl homolog has been obtained[59a] from methanesulfonic anhydride and ethyl alcohol. It has the b.p. 85–86° (10 mm.). No other physical properties have been determined. It is easily hydrolyzed by heating with water.

n-Butyl methanesulfonate has been prepared[67a] in 79.5% yield by the addition of pyridine to a mixture of the alcohol and methanesulfonyl chloride kept at 0°. The ester distils at 105–106° (6 mm.) and has the d_4^{20} 1.1074 and n_D^{20} of 1.4319. This compound was found to

$$CH_3SO_2Cl + C_4H_9OH + C_5H_5N \rightarrow CH_3SO_3C_4H_9 + C_5H_5NHCl$$

have no advantage as an alkylating agent over *n*-butyl *p*-toluenesulfonate. Several methanesulfonates of carbohydrates have been described by Helferich and co-workers.[67b]

Halomethanesulfonic Acids. A considerable number of halogen derivatives of methanesulfonic acid have been investigated. The reduction of trichloromethanesulfonic acid[68] with zinc and sulfuric acid may be stopped at the intermediate stages. Chloro- and dichloromethanesulfonic acids are also present in the reaction product obtained from potassium sulfite and chloroform[86b] at 180°. Sodium chloromethanesulfonate is readily obtained by refluxing chlorobromomethane with aqueous sodium sulfite solution.[69a]

$$ClCH_2Br + Na_2SO_3 \rightarrow ClCH_2SO_3Na + NaBr$$

Evaporating the reaction mixture to dryness and extracting with alcohol separates the sulfonate from inorganic salts. Barium chloromethanesulfonate has been obtained by the oxidation of chloromethyl thiocyanate with fuming nitric acid and the addition of barium hydroxide to the solution. The sodium salt is very soluble in water, the barium salt much less so. The free acid has apparently not been obtained in a pure condition although a very concentrated solution of it was described[68] as a strongly acidic syrup. At 200° sodium chloromethanesulfonate reacts with sodium oleate and other fatty acid salts[69b] to give a product useful as a detergent or wetting agent. Chloromethanesulfonyl chloride has been prepared from trithiane and chlorine water.[69c] The corresponding amide undergoes a rapid decomposition with dilute alkali, probably through initial cleavage of the carbon-sulfur bond.[69c] The chlorine of the free acid is unusually inert. Heating the amide with acetic anhydride or benzoyl chloride gives the N-acyl derivative.[69d] The N-benzoylchloromethanesulfonamide has a sweet taste.

$$C_{17}H_{33}COONa + ClCH_2SO_3Na \rightarrow C_{17}H_{33}COOCH_2SO_3Na + NaCl$$

$$ClCH_2SO_2NH_2 + OH^- \rightarrow [ClCH_2OH] + [SO_2NH_2]^- \rightarrow NH_4Cl + HCHO + HSO_3^-$$

Dichloromethanesulfonyl chloride,[70] obtained from the potassium salt and phosphorus pentachloride, is reduced in alcoholic solution by sulfur dioxide to the sulfinic acid.

Chlorine reacts with moist carbon disulfide[68] to form trichloromethanesulfonyl chloride, a compound also obtained by oxidation of

$$CS_2 + 5Cl_2 + 2H_2O \rightarrow CCl_3SO_2Cl + 4HCl + SCl_2$$

trichloromethylsulfur chloride with nitric acid.[71] This acid chloride forms camphor-like easily sublimed crystals which melt at 135° and

$$CCl_3SCl + 4HNO_3 \rightarrow CCl_3SO_2Cl + 4NO_2 + 2H_2O$$

the liquid distils at 170°. It can be recrystallized from boiling water or dilute alcohol without appreciable decomposition, but upon boiling with water for some time, however, decomposition becomes apparent,[72] the products being carbon dioxide, sulfur dioxide, sulfuric acid, hydrochloric acid, and chloroform. The products indicate that hydrolysis must occur in at least two ways.

$$Cl_3CSO_2Cl + H_2O \rightarrow [Cl_3COH] + HCl + SO_2$$
$$[Cl_3COH] + H_2O \rightarrow 3HCl + CO_2$$
$$Cl_3CSO_2Cl + 2H_2O \rightarrow CHCl_3 + H_2SO_4 + HCl$$

With barium hydroxide solution some of the normal hydrolysis product is obtained.

Sulfur dioxide reduces the acid chloride to the sulfinic acid as with the dichloro compound. The sulfinic acid is quite unstable.

$$Cl_3CSO_2Cl + H_2SO_3 + H_2O \rightarrow Cl_3CSO_2H + HCl + H_2SO_4$$
$$Cl_3CSO_2H \rightarrow CHCl_3 + SO_2$$

Aniline likewise acts as a reducing agent, the water-insoluble aniline salt of the sulfinic acid separating out. The oxidation product was not isolated. For *o*-phenylenediamine the oxidation product was probably 2,3-diaminophenazine hydrochloride. With ammonia the products are nitrogen, the ammonium sulfinatc ($Cl_3CSO_2NH_4$), and ammonium chloride. In no case was an amide formed in the reaction with an amine. This reactivity toward amines is in contradiction of the earlier report of Hantzsch,[73] who described the compound as being practically inert toward ammonia and amines. The different results reported are quite probably due to different experimental conditions. With benzene and aluminum chloride triphenylcarbinol results. In these various reactions the $-SO_2Cl$ group behaves as a pseudo-halogen which may be split off either as a positive or negative radical, depending upon the reaction conditions.

Bromomethanesulfonic acid results from the decomposition of bromosulfoacetic acid [74] in aqueous solution under pressure at 200°. Heat-

$$HO_3SCHBrCOOH \xrightarrow[200°]{H_2O} CH_2BrSO_3H + CO_2$$

ing the compound alone at its melting point gives dibromomethanesulfonic acid.

$$2HO_3SCHBrCOOH \rightarrow HO_3SCH_2COOH + CHBr_2SO_3H + CO_2$$

The dibromo compound has also been obtained by bromination of barium sulfoacetate.[75a] The barium salt crystallizes with one molecule of water.

$$2(CH_2SO_3CO_2)Ba + 4Br_2 \rightarrow (CHBr_2SO_3)_2Ba + BaBr_2 + 2HBr + 2CO_2$$

According to a German patent[75b] sodium dibromomethanesulfonate results in 60% yield from bromination of sodium acetonesulfonate and heating the product with water or alcohol.

$$CH_3COCH_2SO_3Na + 4Br_2 \rightarrow CHBr_2COCBr_2SO_3Na + 4HBr$$
$$CHBr_2SO_3CBr_2SO_3Na + H_2O \rightarrow CHBr_2SO_3Na + CHBr_2COOH$$

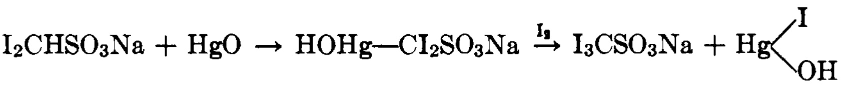
Salts of the iodomethanesulfonic acids have quite recently received considerable attention because of their possible use as x-ray contrast reagents in urologic practice.[76] The sodium salt of iodomethanesulfonic acid has been prepared in nearly quantitative yield by the action of iodoform[77] upon an aqueous solution of sodium sulfite. The reaction of methylene iodide with various sulfites has also been patented.[77d, 78] Another reaction which has received considerable study consists of the replacement of the chlorine of chloromethanesulfonic acid with iodine[79] by heating with an iodide.

$$(ClCH_2SO_3)_2Zn + ZnI_2 \rightarrow (ICH_2SO_3)_2Zn + ZnCl_2$$

The substitution of the bromo or fluoro compound for chloromethanesulfonic acid in this reaction has also been mentioned.[80] The iodomethanesulfonate may be separated from the other salts in the reaction mixture by treatment with ethyl alcohol, in which the sulfonate is quite soluble.

Barium diiodomethanesulfonate results in 30% yield by heating barium sulfoacetate with iodine, barium iodide, and barium iodate in aqueous solution[81] in a sealed tube at 200–210° for 8 hours. The free acid melts at 61°. The barium salt forms several hydrates.

By treatment of sodium methanesulfonate or its mono or diiodo compounds with iodine and sodium carbonate in water solution at 150–180° it is claimed[82] that the triiodo compound is produced. A better method is to treat the diiodo compound with mercuric oxide and decompose the product with iodine.[83]



$$I_2CHSO_3Na + HgO \rightarrow HOHg{-}CI_2SO_3Na \xrightarrow{I_2} I_3CSO_3Na + Hg\begin{matrix} / I \\ \backslash OH \end{matrix}$$

The sodium salt ($2H_2O$) is readily soluble in water. It is considerably more toxic than the mono and diiodo compounds, behaving in many respects like iodoform. The iodine atoms are even more labile than those of iodoform, oxidation by atmospheric oxygen in alcohol solution liberating free iodine in a few minutes. Reaction with the oxygen in the blood occurs much more slowly. In water or alcohol solution when kept in the dark in an inert atmosphere decomposition is negligible. The action of light in the absence of oxygen liberates hydrogen iodide and sodium bisulfate.

$$I_3CSO_3Na + 3H_2O \xrightarrow{\text{light}} 3HI + NaHSO_4 + HCOOH$$

A side reaction also occurs.

$$I_3CSO_3Na + 3H_2O \rightarrow 3HI + NaHSO_3 + H_2CO_3$$

Several mixed halogen derivatives of methanesulfonic acid have been investigated, particularly in regard to their resolution into optical isomers. Barium chlorobromomethanesulfonate is obtained by the bromination of chlorosulfoacetic acid [81] at 150° and neutralizing the reaction mixture with barium carbonate. Some difficulty was encountered [84] in attempting to resolve the acid into its optical isomers, this finally being accomplished [85] by hydroxyhydrindamine. Furthermore, the active forms racemize with great ease, possibly because of lability of the hydrogen attached to the asymmetric carbon atom. This would be due to ionization rather than enolization, since hydrogen adjacent to sulfur-oxygen bonds of this type does not tend to exist in the enol form. Because of this optical lability it was possible to convert the *dl* compound completely into the *l*- salt of *l*-hydroxyhydrindamine which crystallizes out of acetone. Various salts of either active form exhibit mutarotation in solution.

$$ClCHSO_3HCOOH + Br_2 \rightarrow ClCHBrSO_3H + CO_2 + HBr$$

Chloroiodomethanesulfonic acid may be obtained in a 60% yield by iodination [81] of chlorosulfoacetic acid at a temperature of 190° with iodine and barium iodate. Its optically active forms do not racemize as readily [84,86] as is the case with the chlorobromo compound.

Iodination of bromosulfoacetic acid at 210° gives a small yield of bromoiodomethanesulfonic acid.[81]

Ethanesulfonic Acid. Only the reactions not mentioned in the discussion of general methods for preparing sulfonic acids are given here. Shaking ethyl sulfite with ethyl iodide [54] in alkaline solution or even hydrolysis of ethyl sulfite with cold 20% alkali [87] gives some of the alkali ethanesulfonate. The action of ethyl iodide upon sodium ethyl sulfite at 150° gives similar results. Sodium ethyl sulfite rearranges in the presence of salts such as sodium thiocyanate to form sodium ethanesulfonate.[88] Sodium sulfite may be alkylated[89] with sodium ethyl sulfate by heating in concentrated aqueous solution to 110–120°

$$Na_2SO_3 + C_2H_5NaSO_4 \rightarrow C_2H_5SO_3Na + Na_2SO_4$$

for 3 hours. Sodium ethylenesulfonate is reduced[90] by hydrogen iodide and phosphorus to the ethanesulfonic acid salt.

$$CH_2{=}CHSO_3Na \xrightarrow{2(H)} CH_3CH_2SO_3Na$$

As has already been noted, ethanesulfonic acid is stable toward chlorine. When heated with solid alkali[91] ethylene is evolved. This reaction is different from that obtained in dilute alkali solution by

$$C_2H_5SO_3Na + KOH \rightarrow NaKSO_3 + C_2H_4 + H_2O$$

Wagner and Reid[19] who found that aliphatic sulfonic acids were first converted to the corresponding alcohols followed by oxidation to the acids.

Ethanesulfonyl chloride has been prepared by the action of phosphorus pentachloride[92] upon sodium ethanesulfonate, a reagent which at higher temperature[93] produces ethyl chloride. Thionyl chloride has

$$C_2H_5SO_2Cl + PCl_5 \rightarrow C_2H_5Cl + SOCl_2 + POCl_3$$

likewise been employed[41] in preparing the acid chloride. It also results, among other things, from the action of chlorine water upon ethyl sulfoxide,[49] and other sulfur compounds.[35b–c]

With zinc dust in alcohol[94] ethanesulfonyl chloride is reduced to

$$2C_2H_5SO_2Cl + 2Zn \rightarrow (C_2H_5SO_2)_2Zn + ZnCl_2$$

zinc ethanesulfinate while in the presence of sulfuric acid[95] reduction goes to the thiol stage.

$$C_2H_5SO_2Cl + 3Zn + 3H_2SO_4 \rightarrow C_2H_5SH + 3ZnSO_4 + 2H_2O + HCl$$

It is hydrolyzed slowly by water.[95] In the reaction with hot ethyl alcohol there are formed, besides ethyl ethanesulfonate, ethyl chloride and sulfur dioxide.[96] This is an unusual reaction for a sulfonyl chloride of this type. The addition product with aluminum chloride[41] also decomposes in this manner, hydrogen chloride and a resin being formed as by-products. By warming with a 70% potassium fluoride solution[48] a 67% yield of the corresponding fluoride, b.p. 134–135°, results. This has no action upon pyridine even after standing for weeks.

The amide results by the action of ammonia[97] on the chloride in the usual manner. At a low temperature a mixture of nitric and sulfuric acids reacts with ethanesulfonamide to form the nitramide, but nitric acid alone at a higher temperature reacts explosively with evolution of nitrous oxide.

$$C_2H_5SO_2NH_2 + HNO_3 \rightarrow C_2H_5SO_2NHNO_2 + H_2O$$

$$C_2H_5SO_2NH_2 + HNO_3 \rightarrow C_2H_5SO_3H + N_2O + H_2O$$

The methyl and ethyl esters of ethanesulfonic acid have been prepared[98] by the action of the sodium alkoxide with ethanesulfonyl chloride in alcohol solution. The ethyl ester also results from silver

$$C_2H_5SO_2Cl + RONa \rightarrow C_2H_5SO_3R + NaCl$$

sulfite and ethyl iodide,[99] one sulfur to carbon bond being established.

$$Ag_2SO_3 + 2C_2H_5I \rightarrow C_2H_5SO_2OC_2H_5 + 2AgI$$

Only the boiling point[98] of the methyl ester, 197.5–200.5°, has been reported, but the physical properties of the ethyl homolog have been determined with some care. It distils at 213–213.5° (761 mm.);[100] 121.5° (25 mm.);[101] and 104° (14 mm.).[102] The d_4^{22} is 1.14517[100] and d_0^0 has been given[98] as 1.1712. The dielectric constant was found by Walden[102] to be 45.5 at 1.2° and 41.9 at 20°, values which are higher than those of all but a few other organic compounds. The surface tension determinations[101] as well as the high boiling point indicate association in the liquid state. The absorption spectrum for the ultraviolet has been studied.[103]

Reaction of ethyl ethanesulfonate with potassium iodide[89] gives ethyl iodide and a double salt.

$$4C_2H_5SO_2OC_2H_5 + 5KI \rightarrow 4C_2H_5I + (C_2H_5SO_3K)_4 \cdot KI$$

With phenylmagnesium bromide some ethylbenzene[104] together with considerable ethyl phenyl sulfone[105] result.

$$C_6H_5MgBr + C_2H_5SO_2OC_2H_5 \rightarrow C_6H_5C_2H_5 + C_2H_5SO_2OMgBr$$

$$C_6H_5MgBr + C_2H_5SO_2OC_2H_5 \rightarrow C_6H_5SO_2C_2H_5 + C_2H_5OMgBr$$

Its alkylating action is also shown in the reaction with aqueous or alcoholic ammonia.[106]

$$C_2H_5SO_2OC_2H_5 + NH_3 \rightarrow C_2H_5SO_2ONH_3C_2H_5$$

The rate of reaction with sodium ethoxide[107] has been studied in some detail.

$$C_2H_5SO_3C_2H_5 + C_2H_5ONa \rightarrow (C_2H_5)_2O + C_2H_5SO_3Na$$

Haloethanesulfonic Acids. 2-Chloroethanesulfonic acid[108] and the corresponding bromo[109] compound are obtained as their alkali salts by heating an excess of the ethylene halide with sodium or potassium sulfite in an alcohol-water mixture, and by addition of the hydrogen halide[110] to ethylenesulfonic acid. The chloro compound also results from hydrolysis of the acid chloride which was obtained[111] from potas-

$$CH_2{=}CHSO_3H + HX \rightarrow XCH_2CH_2SO_3H$$

sium isethionate. Heating ethane-1,2-disulfonyl chloride alone gives

$$HOCH_2CH_2SO_3K + 2PCl_5 \rightarrow ClCH_2CH_2SO_2Cl + 2POCl_3 + KCl + HCl$$

this same acid chloride, while with acetamide[112a] ammonium 2-chloro-

$$(CH_2SO_2Cl)_2 \rightarrow ClCH_2CH_2SO_2Cl + SO_2$$

$$ClCH_2CH_2Br + KSCN \rightarrow ClCH_2CH_2SCN + KBr$$

$$ClCH_2CH_2SCN + 13HNO_3 \rightarrow ClCH_2CH_2SO_3H + CO_2 + 14NO_2 + 6H_2O$$

ethane-1-sulfonate results. Another method of preparation utilizes ethylene chlorobromide.[113]

The silver salt is stable in water solution at ordinary temperatures but silver chloride precipitates from the boiling solution. Sodium 2-bromoethane-1-sulfonate[114] is slightly hygroscopic. The properties of the crystals of several other salts of the bromo compound have been studied in detail.[115] The reaction of the halosulfonic acids with ammonia and amines is given under taurine.

1-Chloroethane-1-sulfonic acid has been obtained in small yields by the action of sodium sulfite upon ethylidene chloride.[116] Acetaldehyde and aldehyde resins were present as by-products. The sulfonyl chloride is formed in 50% yield when β-trithio-*para*-acetaldehyde is chlorinated[69d, 117] in water suspension or in glacial acetic acid. With boiling water this is converted into the sulfonic acid. Boiling methanol yields the same product but with boiling ethanol no change occurs, a temperature of 130° being necessary for reaction to take place. Acid formation probably occurs through the ester.

$$CH_3CHClSO_2Cl + ROH \rightarrow CH_3CHClSO_3R + HCl$$

$$CH_3CHClSO_3R + ROH \rightarrow CH_3CHClSO_3H + R_2O$$

With sodium methoxide it is possible to obtain the methyl ester in a pure state.

Treating 1-chloroethane-1-sulfonyl chloride with phosphorus pentachloride at 200° in a sealed tube yields 1,1-dichloroethane. By reduction the thiol is formed apparently without removing the halogen. An attempt to prepare the sulfinate by the action of zinc dust gave zinc ethanesulfonate. This reaction does not occur, however, unless a trace of water is present. The sulfonyl chloride distils at 70° (13 mm.) and the amide[69d, 117] melts at 66°. Other reactions of this compound and the corresponding hydroxy compound are involved in the controversy concerning the structure of aldehyde bisulfite addition products and will be discussed later.

1,2-Dibromoethanesulfonic acid is obtained by addition of hydrogen bromide to an unsaturated acid.[112b]

$$CH_2{=\!=}CBrSO_3K + HBr \rightarrow BrCH_2CHBrSO_3K$$

This hydrolyzes slowly in boiling water solution while with alkali the

$$CH_2BrCHBrSO_3K + H_2O \rightarrow HOCH_2CHBrSO_3K + HBr$$

other bromine and the sulfonate group are removed.

$$BrCH_2CHBrSO_3K + 2KOH \rightarrow BrCH_2CHO + KBr + K_2SO_3 + H_2O$$

Zinc dust removes both bromines readily.

$$BrCH_2CHBrSO_3K + Zn \rightarrow CH_2{=\!=}CHSO_3K + ZnBr_2$$

Potassium 1,2-dibromoethanesulfonate is only slightly soluble in cold water and insoluble in alcohol.

2-Chloro-1-bromoethane-1-sulfonic acid results from addition of hydrogen chloride to the unsaturated compound[117] mentioned above. The acid chloride was obtained as an oil.

Higher Alkanesulfonic Acids

The methods used in preparing the straight-chain sulfonic acids with a terminal sulfo group have already been described.[24b, 25, 26, 28] The physical properties of aqueous solutions of these acids and their salts have received extensive investigation, chiefly at the hands of McBain and Tartar and their co-workers[24b, 118] in recent years. These compounds exhibit the properties of colloidal electrolytes. The first departure from the behavior of ordinary electrolytes was observed with the seven-carbon acid in solutions above 0.4 *N* while with the higher members of the series only in extreme dilution does the Debye-Hückel-Onsager behavior hold.

A more detailed description of the properties of 1-hexadecanesulfonic acid[24b] will aid in visualizing the properties of the long-chain sulfonic acids. Although the free acid is difficult to obtain pure from water or ethyl alcohol solutions, it can be crystallized from ether to give a white solid of m.p. 53–54°. It is only slightly soluble in water at room temperature but it dissolves readily above 50° and in the ordinary organic solvents at room temperature. An 0.0008 *N* aqueous solution is slightly turbid but the 0.3 *N* solution is a gelatinous mass which does not flow. The solutions are clear at 90° even after long standing. At 90° a 1.0 *N* solution is so viscous that bubbles of hydrogen rise through it very slowly.[24b] The degree of dissociation as measured by conductivity is about 25% for 0.1 *Nw*, 85% for 0.0001 *Nw*, and 30% for 0.5 *Nw* solution which is similar to the behavior of sodium and potassium soaps. The degrees of dissociation at 90° calculated by conductivity, lowering of vapor pressure, and emf measurements are 29.8, 38.4, and 63% respectively. These results have been discussed by McBain and Williams.[24b] The conductimetric titration is similar to that of hydrochloric acid.[25]

The sodium salt is soluble in hot water to give a soapy solution while the barium salt is only four times as soluble as barium sulfate. The solubilities of a considerable number of salts have been reported.[28c, 118g] In general, the sodium salts of the higher alkanesulfonic acids show rapid increases in solubility in a temperature range that is characteristic for each salt. Thus from 37° to 47.5° the solubility of sodium 1-hexadecanesulfonate increases from 0.013 to 0.035 g. per 100 g. of water, while from 50° to 62° the increase is from 0.1 g. to 11.6 g.[118g] With sodium octadecanesulfonate temperatures about 10° higher are necessary to reach these solubilities. Extensive data are given in the original literature.

ARYLALKANESULFONIC ACIDS

Sulfonic acids in which the sulfo group is attached to the side chain of an aromatic nucleus may well be considered here. Since the benzene ring sulfonates more readily than most aliphatic groups these are not usually prepared by direct substitution reactions. Toluene-ω-sulfonic acid [69d, 119] is most readily obtained from benzyl chloride and an alkali sulfite in alkaline solution. It has also been obtained by heating benzyl chloride with a solution of sodium hydrosulfite in the presence of zinc dust,[120] by oxidation of benzyl disulfide with nitric acid [121] and from heating methyl benzyl ketone with concentrated sulfuric acid.[122] The free acid forms hygroscopic crystals. In aqueous solution it is

$$C_6H_5CH_2COCH_3 + H_2SO_4 \rightarrow C_6H_5CH_2SO_3H + CH_3COOH$$

highly ionized.[128] Oxidation with hydrogen peroxide [62] removes the sulfo group, benzaldehyde resulting. Fusion with potassium hydroxide produces a complex mixture [124] of substances from which were separated benzene, toluene, potassium benzoate, potassium sulfite, and a solid of undetermined composition melting at 110°. The sodium salt upon pyrolysis [119c] gives tetraphenylthiophene, stilbene, benzaldehyde, benzoic acid, sulfur, and sulfur dioxide. When heated with potassium cyanide [121] the sulfonate group is replaced.

$$C_6H_5CH_2SO_3Na + KCN \rightarrow C_6H_5CH_2CN + KNaSO_3$$

By warming with phosphorus pentachloride alone [125] or in the presence of some phosphorus oxychloride [119d] toluene-ω-sulfonyl chloride is produced, but at a higher temperature benzyl chloride results. The chlorination of benzyl isothiourea or thiocyanate also gives the sulfonyl chloride.[35b–e] The fluoride, m.p. 90–91°, has been prepared by the action of potassium fluoride upon the sulfonyl chloride.[48] Upon standing, the sodium salt slowly evolves benzaldehyde.[119c]

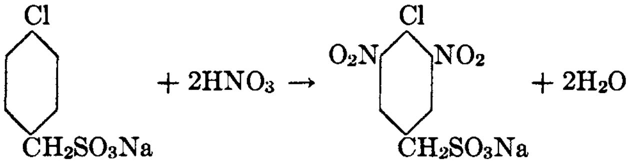
Thermal decomposition of the sulfonyl chloride eliminates sulfur dioxide.[125] Reduction with zinc in alcohol gives, besides the sulfinic

$$C_6H_5CH_2SO_2Cl \rightarrow C_6H_5CH_2Cl + SO_2$$

acid, benzyl sulfone, benzaldehyde, and sulfur dioxide.[119c] Reaction with triethylamine in the absence of air [126] gives stilbene as one product.

Toluene-ω-sulfonamide, prepared from the sulfonyl chloride and ammonia or ammonium carbonate, alkylates readily [119d] when treated with alkali and an alkyl iodide or α-halogenated ester. With hydrogen iodide and phosphonium iodide [127a] at 85–100° the amide is reduced to benzyl iodide and hydrogen sulfide. A series of N-alkylsulfonamides prepared from aliphatic amines and the sulfonyl chloride have been suggested as derivatives for identifying the amines.[127b]

Chlorination of sodium toluene-ω-sulfonate in cold aqueous solution gives a mixture of the 2- and 4-chloro compounds.[128] In hot solution a mixture of 2,5-, 2,4-, and 3,4-dichloro compounds results, and a long-continued chlorination yields chiefly 2,4,5-trichlorotoluene-ω-sulfonic acid. The structures of these chlorinated products follow from their oxidation to the corresponding chlorobenzoic acids. The 2-chloro compound has also been prepared from the action of sodium sulfite upon 2-chlorobenzyl chloride [129] and the 4-chloro isomer similarly from 4-chlorobenzyl bromide.[130a] Nitration [130b] gives, with the former compound, 2-chloro-5-nitrotoluene-ω-sulfonic acid. The 4-chloro isomer dinitrates [131] to the 3,5-dinitro compound.



Sodium *p*-bromotoluene-ω-sulfonate has been prepared[132] similarly to the chloro compound and also by the diazo reaction.[119b] Nitration[119a,b,133] of sodium toluene-ω-sulfonate gives chiefly the 4-isomer together with some of the 2- and 3-compounds, and further reaction forms the 2,4-dinitro derivative. All three mononitro compounds have also been prepared by action of sodium sulfite upon the corresponding benzyl halides.[134] By reduction of the nitro group various compounds were obtained which are of no particular interest, however, from the standpoint of sulfur chemistry. 2-Chlorotoluene-ω-sulfonyl chloride upon chlorination at 150–180° gives 2-chlorobenzotrichloride.[135] *p*-Nitrotoluene-ω-sulfonyl chloride loses sulfur dioxide when heated to 130°.[119b] Sodium *p*-methyltoluene-ω-sulfonate has been prepared from *p*-methylbenzyl chloride and sodium sulfite.[136]

The two isomeric phenylethanesulfonic acids and the alpha sulfo derivatives of 1-phenylpropane and *n*-butane have been prepared[12c,137] from the corresponding bromides and/or chlorides. When 1-bromo-1-phenylethane is refluxed with ammonium sulfite styrene is formed and this reacts with ammonium bisulfite to yield 1-phenylethane-2-sulfonic acid, but if the reaction is carried out at room temperature in the presence of excess ammonia a 50% yield of the normal reaction product results.[12c] The action of phosphorus pentachloride upon a 1-phenylethane-1-sulfonate has been reported[12c] to give 1-phenyl-1-chloroethane, although earlier[137] the sulfonyl chloride was mentioned as melting at 79°. 1-(2,4-Dichlorophenyl)-1-chloroethane with sodium sulfite gives only the alcohol. Resolution of the *dl* forms of the sulfonic acids mentioned above was accomplished in the usual fashion.

Diphenylchloromethane with aqueous sodium sulfite gives the ether[138] rather than the sodium sulfonate. The sulfonic acid has been

$$(C_6H_5)_2CHCl + H_2O \rightarrow (C_6H_5CH)_2O + 2HCl$$

obtained, however, by hydrolysis of the ester obtained from the reaction of diphenyldiazomethane with alcoholic sulfur dioxide.[139a]

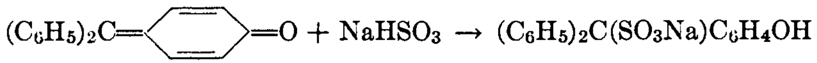
$$(C_6H_5)_2CN_2 + CH_3OH + SO_2 \rightarrow (C_6H_5)_2CHSO_3CH_3 + N_2$$
$$(C_6H_5)_2CHSO_3CH_3 + H_2O \rightarrow (C_6H_5)_2CHSO_3H + CH_3OH$$

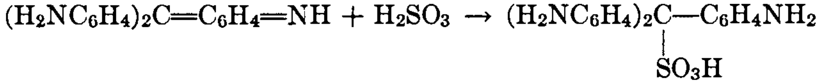
In a patent it is claimed[139b] that arylolefins such as styrene, safrole, and indene react with chlorosulfonic acid in ether to yield sulfonic acids containing chlorine. Structures of the products were not given.

A number of triarylmethanesulfonic acids are known of which the most interesting are the compounds involved in the Schiff's reagent test for aldehydes. Triphenylmethylcarbinol[140] and the corresponding *p*-tolyl compound react very slowly with a slightly acidified sodium bisulfite solution to give the sodium sulfonates. Tri-*p*-anisylcarbinol reacts in a few minutes under the same conditions.

$$(C_6H_5)_3COH + NaHSO_3 \rightarrow (C_6H_5)_3CSO_3Na + H_2O$$

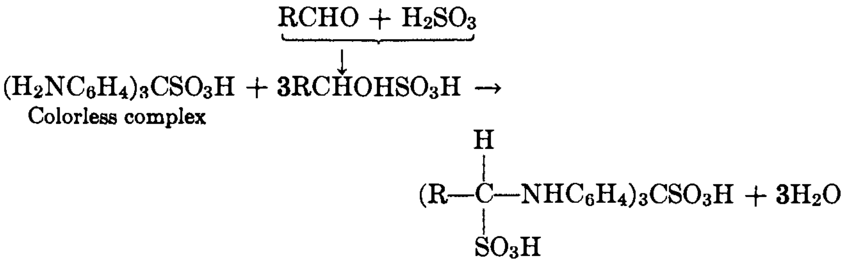
Sodium *p*-anisyldiphenylmethanesulfonate results from the action of sodium sulfite upon the chloride.[141] The corresponding *p*-hydroxy compound is formed from the action of sodium bisulfite upon fuchsone. The salts of these sulfonic acids are stable in neutral or alkaline solution but upon boiling with acid the triarylcarbinol and sulfur dioxide are formed. Amino- and dialkylaminotriarylmethanesulfonic acids result from the action of sulfurous acid upon dyestuffs of the malachite green and pararosaniline type.[142] Either the free base or a salt may be used. The sulfonic acids are unstable, being decomposed either by acid or alkali upon boiling. Heating the colorless solution of one of these sulfonic acids results in a reversible decomposition with formation of the dye.[143] Recombination occurs on cooling. The light-colored crystals of the hydrochloride turn violet in the air owing to formation of the salt of the dye with the leuco-sulfonic acid.





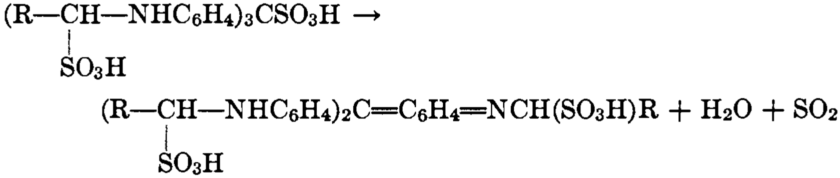
$$(H_2NC_6H_4)_2C{=}C_6H_4{=}NH + H_2SO_3 \rightarrow (H_2NC_6H_4)_2\underset{\displaystyle SO_3H}{C}{-}C_6H_4NH_2$$

The nature of the reaction involving an aldehyde, a solution containing the sulfonic acid from fuchsin, and excess sulfur dioxide has been very carefully investigated.[144] The results are summarized in the equations.



$$\underset{\text{Colorless complex}}{(H_2NC_6H_4)_3CSO_3H} + 3\overset{\substack{\underbrace{RCHO + H_2SO_3}\\ \downarrow}}{RCHOHSO_3H} \rightarrow (R{-}\underset{SO_3H}{\overset{H}{C}}{-}NHC_6H_4)_3CSO_3H + 3H_2O$$

Where the aldehyde is formaldehyde all the amino groups react, while with other aldehydes only two enter into the condensation. This condensation product is unstable and reverts to a quinoid form with loss of sulfur dioxide and water.



$$(R-\underset{\substack{|\\ SO_3H}}{CH}-NHC_6H_4)_3CSO_3H \rightarrow$$

$$(R-\underset{\substack{|\\ SO_3H}}{CH}-NHC_6H_4)_2C{=}C_6H_4{=}NCH(SO_3H)R + H_2O + SO_2$$

AMINOSULFONIC ACIDS

α-Aminosulfonic Acids. It has been reported[145] that the compounds obtained by the action of amines with the sodium bisulfite addition product of formaldehyde are derivatives of methanesulfonic acid.

$$HCHO + NaHSO_3 + NH_3 \rightarrow NH_2CH_2SO_3Na + H_2O$$

The evidence for this is that the amino compound reacts with nitrosyl chloride to form chloromethanesulfonic acid identical with that from methylene chloride.

$$NH_2CH_2SO_3Na \xrightarrow{NOCl} ClCH_2SO_3Na \xleftarrow{Na_2SO_3} CH_2Cl_2$$

Similar compounds have been made from acetaldehyde, isobutyraldehyde, isovaleraldehyde, benzaldehyde, and substituted benzaldehydes.[146a,d] Schroeter[146b] has claimed that this evidence is not conclusive because the true aminosulfonic acids such as taurine are neutral to phenolphthalein, while those obtained from aldehydes are monobasic acids. It was further claimed by Schroeter that a true α-amino acid had been prepared by him and would be described later. This work has apparently not put in its appearance, however. These reactions have a decided bearing upon the structure assigned to bisulfite addition products of aldehydes and ketones. Amides derived from aminomethanesulfonic acid or a similar compound and an acid chloride such as palmityl chloride have been patented as wetting, cleansing, and dispersing agents.[146c] The condensation of aminomethanesulfonic acid with formaldehyde and a sulfonamide[146e] has also been described.

$$NH_2CH_2SO_3Na + C_{17}H_{35}COCl + NaOH \rightarrow C_{17}H_{35}CONHCH_2SO_3Na + NaCl + H_2O$$

Arylaminomethanesulfonic acids have been obtained by the action of an aromatic amine with sodium hydroxymethanesulfonate[147a] and with other aldehyde bisulfite addition compounds.[147b] It is highly probable that the products obtained by the action of sulfurous acid upon a Schiff's base,[147c] and from amine sulfites and aldehydes [147d] also belong in this category. A particularly interesting substance is that obtained from bis-(4-aminophenyl) sulfone, cinnamic aldehyde, and sodium bisulfite; [147e] this and other similar compounds have a sulfanilamide type of pharmacological action.[147f]

$$(H_2NC_6H_4)_2SO_2 + 2C_6H_5CH{=}CHCHO \rightarrow$$
$$(C_6H_5CH{=}CH{-}CH{=}NC_6H_4)_2SO_2 \xrightarrow{NaHSO_3}$$
$$[C_6H_5{-}CH(SO_3Na)CH_2CH(SO_3Na)NHC_6H_4]_2SO_2$$

2-Aminoethanesulfonic Acid: Occurrence and Preparation. In an investigation of the various constituents of ox bile [148] a nitrogen-containing weakly acidic substance was isolated which was found to be soluble in water but only slightly so in alcohol. It was not until considerably later [149] that the presence of sulfur in the compound was noted. Aside from bile in which 2-aminoethane-1-sulfonic acid (taurine) is present as the amide of cholic acid [150,151] it has been found in various [152] parts of several organisms. The best natural source for preparative purposes is said to be the large muscle of the abalone,[152] 74 kg. of muscles yielding 362 g. of taurine. Hydrolysis of sodium tauroglycocholate requires approximately 3 hours of refluxing with 4 *N* hydrochloric acid.[153]

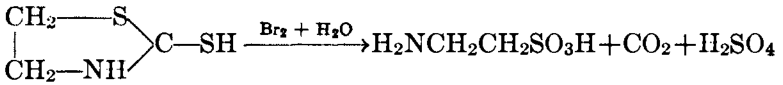
Taurine is probably produced in the animal body from waste sulfur-containing materials as they pass through the liver. The oxidation and decarboxylation of cystine which has been suggested [154] as the natural source of taurine has also been carried out in the laboratory.[155a,b,f] That taurine is a waste product is further indicated by its lack of dietary value as shown by feeding experiments.[155c,d] On the other hand, its presence in blood agar facilitates the growth of certain microorganisms.[155e]

Although the yield of taurine obtained from cystine is fair [155a,b] (59%) this does not furnish a practical method of preparation, since no inexpensive way of obtaining cystine is known. In this connection it is interesting to note that although oxidation of cystine with hydrogen peroxide [155b] gives a 40% yield of taurine, if cystamine hydrochloride is the starting material, most of the sulfur appears as sulfuric acid.

Taurine has been synthesized in a number of ways which do not depend upon naturally occurring substances as starting materials. Strecker [156] claimed that heating ammonium isethionate to 210° gave a small yield of the amino acid. Although this indicated the correct structure, later[157] investigators have been unable to verify this statement. The structure was soon made certain by Kolbe's synthesis[145b,158] from 2-chloroethanesulfonic acid and ammonia. A similar method involving the more readily available sodium 2-bromoethanesulfonate[145b,159] is probably the most satisfactory way of making taurine on a laboratory scale so far devised. The analogous reaction of ammonia with ethionic acid has been patented[160] as a method of preparation.

$$HO_3SOCH_2CH_2SO_3H + 3NH_3 \rightarrow H_2NCH_2CH_2SO_3H + (NH_4)_2SO_4$$

Taurine has also been obtained by the addition of sulfurous acid to ethylene imine,[161a] from 2-bromoethylamine and ammonium or sodium sulfite,[145b,161b,d] by addition of ammonia to sodium ethylenesulfonate,[161c] by oxidation of 2-mercaptothiazoline with bromine water,[162]

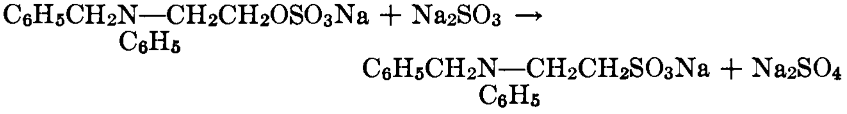


and from acetaldehyde by the series of reactions indicated below.

$$CH_3CHO \xrightarrow{ClSO_3H} HO_3SCH_2CHO \xrightarrow{NH_3} NH_4O_3SCH_2CHOHNH_2 \xrightarrow{-H_2O}$$
$$NH_4O_3SCH_2CH{=}NH \xrightarrow{H_2} HO_3SCH_2CH_2NH_2$$

Taurine and some of its derivatives have been prepared by the action of ammonia or an amine upon isethionic acid or other hydroxysulfonic acid under pressure,[163,164] one patent[165] generalizing the reaction to include a large number of compounds and mentioning the beneficial effect upon the reaction of the presence of a highly ionized neutral or alkaline salt. The acid sulfate ester of ethanolamine or a similar compound may be heated with aqueous sodium sulfite in an autoclave.[166]

$$H_2NCH_2CH_2OSO_3Na + Na_2SO_3 \rightarrow H_2NCH_2CH_2SO_3Na + Na_2SO_4$$



$$\underset{\displaystyle C_6H_5}{C_6H_5CH_2N}—CH_2CH_2OSO_3Na + Na_2SO_3 \rightarrow \underset{\displaystyle C_6H_5}{C_6H_5CH_2N}—CH_2CH_2SO_3Na + Na_2SO_4$$

Many N-alkyl and N-aryl derivatives of taurine have been prepared by the action of an amine upon a 2-haloethanesulfonic acid[145b,167] and some alkyl derivatives by alkylation of taurine with an alkyl iodide[168] or condensation with an aldehyde followed by reduction.[168d] It is claimed in the patent literature[168c] that such compounds may also be made from sulfonated ethers and also by the action of amines upon

$$O(CH_2CH_2SO_3Na)_2 + 2RNH_2 \rightarrow 2RNHC_2H_4SO_3Na + H_2O$$

isethionic acid,[164] as already mentioned. The trimethyl compound of

$$HOCH_2CH_2SO_3Na + (C_2H_5)_2NH \xrightarrow{150-300^\circ} (C_2H_5)_2NCH_2CH_2SO_3Na + H_2O$$

the betaine type has been obtained by methylation of taurine.[169]

2-Aminoethanesulfonic Acid and Derivatives: Properties and Reactions. As already mentioned, taurine is a weakly acidic compound. Determination of the ionization constant has given various values, two more recent [170] ones being 1.8×10^{-9} and 5.77×10^{-10}. Aqueous solutions of taurine have dielectric constants higher than that of water, the increase being linearly proportional to the concentration.[171] Other saltlike compounds in which the positive and negative ions are in the same molecule (dipolar ions) giving rise to permanent dipoles have similar effects.

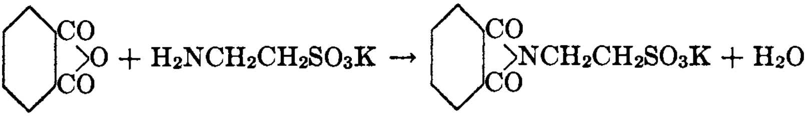
Taurine is remarkably stable to oxidizing agents in acid solution. It is unaffected by sulfuric acid, boiling nitric acid, aqua regia or dry chlorine.[172] The sulfur is completely converted to sulfate, however, by fusion with sodium carbonate and potassium nitrate. When heated to dryness with sodium hydroxide solution, ammonia is evolved practically quantitatively and acidifying the residue gives sulfur dioxide and some acetic acid. It is difficult to account for the presence of the acetic acid if the sulfo group is removed as sulfite. Several reactions must occur simultaneously.

Heating with barium hydroxide solution to 220° gives ammonia and a secondary amine.[173] Boiling a water solution of taurine with excess

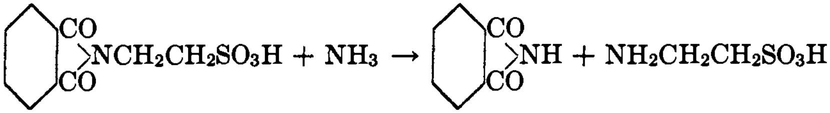
$$(NH_2CH_2CH_2SO_3)_2Ba \rightarrow NH_3 + NH(CH_2CH_2SO_3)_2Ba$$

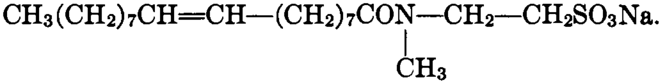
of a suspension of mercuric oxide gives a water-insoluble basic salt with the formula $(NH_2CH_2CH_2SO_3)_2Hg \cdot HgO$, whereas excess taurine forms the soluble normal salt. Various other heavy metal salts have been prepared.[174]

The reaction of taurine with nitrous acid occurs normally with liberation of nitrogen and formation of isethionic acid.[158a] Treatment with cyanamide yields an alcohol-insoluble product similar to the one produced from glycine.[173b] With the azide of cholic acid the naturally occurring taurocholic acid results.[175] By heating with phthalic anhydride or succinic acid the corresponding imide is formed.[176]



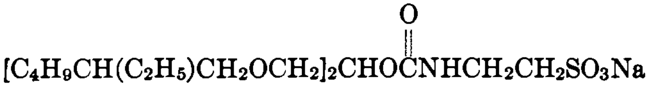
These imides are decomposed by heating with alcoholic ammonia at 120°.



Acetic anhydride converts the sodium salt of taurine into the acetyl derivative.[168b] Benzoylation [177] is conveniently carried out in aqueous barium hydroxide with benzoyl chloride. This amide hydrolyzes easily. Amides derived from the combination of taurine and its N-alkyl derivatives with high-molecular-weight, fatty, or sulfonic acids such as oleic or octadecanesulfonic are of value as wetting, cleansing, and dispersing agents.[178] Of the compounds of this type the most important is the one marketed as Igepon T, which has the structure  $CH_3(CH_2)_7CH{=}CH{-}(CH_2)_7CO\underset{\displaystyle CH_3}{\underset{|}{N}}{-}CH_2{-}CH_2SO_3Na$. This is a neutral salt with good detergent properties which is stable in both acidic and alkaline solutions.[178c]

A number of other types of long-chain groups have been attached to the nitrogen of taurine through a variety of reagents.[179] Formulas for some of these compounds are shown.

$C_{17}H_{33}NHCONHCH_2CH_2SO_3Na$



$[C_4H_9CH(C_2H_5)CH_2OCH_2]_2CHO\overset{\displaystyle O}{\overset{\|}{C}}NHCH_2CH_2SO_3Na$

$(C_{12}H_{25}NHCONHCH_2CH_2)_2NCH_2CH_2SO_3Na$

$p\text{-}C_8H_{17}C_6H_4OCH_2CONHCH_2CH_2SO_3Na$

$\text{abietyl-O}\overset{\displaystyle O}{\overset{\|}{C}}NHCH_2CH_2SO_3Na$

$RCONHCH_2NHCH_2CH_2SO_3Na$

The compounds obtained from the reaction of N-methyltaurine with octadecyl isothiocyanate,[179b] alkyl chloroformates,[179g] and formaldehyde with an amide [179h] have likewise been patented.

$C_{18}H_{37}NHCSN(CH_3)CH_2CH_2SO_3Na$

$ROCON(CH_3)CH_2CH_2SO_3Na$

$C_{17}H_{33}CONHCH_2N(CH_3)CH_2CH_2SO_3Na$

Condensation of an α-bromoacyl bromide with taurine in alkaline solution followed by treatment of the reaction product with ammonia yields a dipeptide.[180a] Glycyl and *dl*-leucyltaurine have been obtained in this manner.

Taurine in water solution reacts with phenyl isocyanate to give the urea derivative[180b] which is characterized by a barium salt only slightly soluble in water. The free acid is readily soluble. 2-Naphthyl isocyanate[181a] behaves similarly.

$$C_6H_5NCO + H_2NCH_2CH_2SO_3H \rightarrow C_6H_5NHCONHCH_2CH_2SO_3H$$

Taurine is reported[181b] to give a strong pyrrole test.

The N-alkyl derivatives of taurine are weak acids similar to taurine except for the trimethyl compound, which is of the betaine type[169] and hence neutral. N-Methyltaurine shows an abnormal reactivity toward nitrous acid in that nitrogen is reported[167a] as one of the products. Reaction with cyanamide takes place as with taurine.

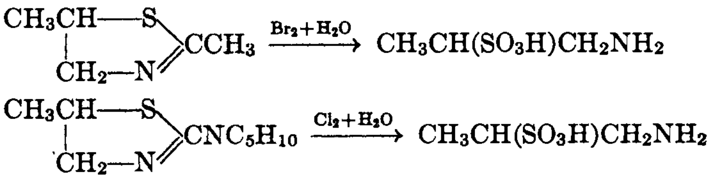
$$CH_3NHCH_2CH_2SO_3H + N{\equiv}C{-}NH_2 \rightarrow H_2NC({=}NH)N(CH_3)CH_2CH_2SO_3H$$

The N-chloro compounds, $RNClCH_2CH_2SO_3H$, have been patented as bleaching agents.[182]

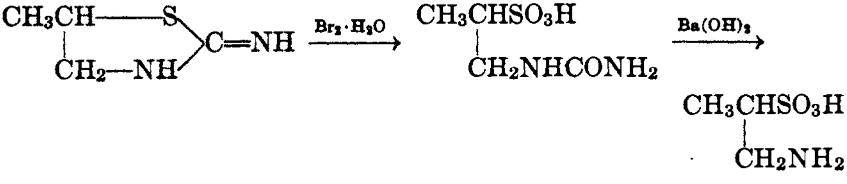
The trimethyl compound is characterized by the great ease with which it is decomposed by aqueous alkali[167b] or even upon boiling in alcohol.[168a]

$$(CH_3)_3\overset{+}{N}CH_2CH_2SO_3^- + NaOH \rightarrow (CH_3)_3N + HOCH_2CH_2SO_3Na$$

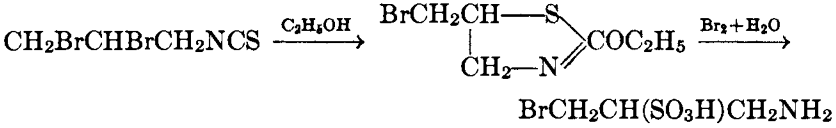
Homologs of Taurine. A few other amino acids of the taurine type may be mentioned briefly here. 1-Aminopropane-2-sulfonic acid has been prepared by oxidizing a dimethylthiazoline[183] or the corresponding methylpiperidine compound.[184]



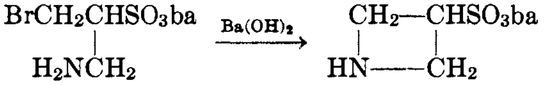
The iminomethylthiazoline requires two steps to convert it to the sulfonic acid.[185]



The addition of sulfurous acid to propylene imine likewise yields a sulfonic acid.[186] 3-Bromo-1-aminopropane-2-sulfonic acid has been prepared by the following sequence of reactions.[187a] Reduction with

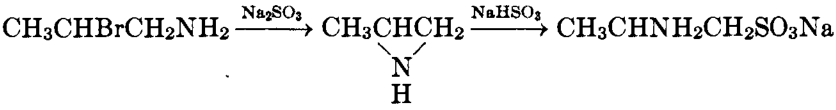


zinc and sulfuric acid replaces the bromine with hydrogen. Alcoholic potassium hydroxide splits out hydrogen bromide. Barium hydroxide in water gives the cyclic imino compound which may also be the product with the potassium hydroxide.



Treating this with hydrogen bromide regenerates the original compound.

An attempt to prepare 1-aminopropane-2-sulfonic acid by the action of sodium sulfite upon 2-bromo-1-propylamine gave the isomeric 2-aminopropane-1-sulfonic acid.[145b] This probably occurs through intermediate formation of the imine.



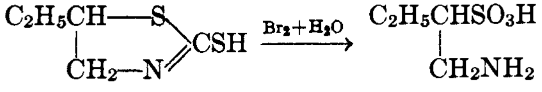
This acid and its N-alkyl derivatives may also be obtained by reduction of the addition product (or mixture) of an amine or ammonia with sodium acetonesulfonate.[187b] A β-sulfonated isopropyl ether reacts

$$CH_3COCH_2SO_3Na + NH_3 \xrightarrow{H_2} CH_3CHNH_2CH_2SO_3Na + H_2O$$

with an aliphatic amine under pressure and high temperature[168a] with loss of the oxygen.

$$O[CH(CH_3)CH_2SO_3Na]_2 + 2C_4H_9NH_2 \rightarrow 2C_4H_9NHCH(CH_3)CH_2SO_3Na + H_2O$$

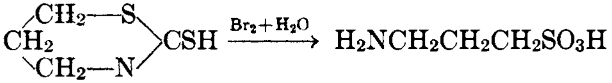
1-Aminobutane-2-sulfonic acid is formed by oxidation of a thiolethylthiazoline.[188]

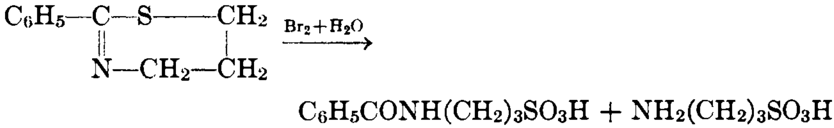


The action of 40% aqueous methylamine upon sodium 2-butene-1,4-disulfonate in an autoclave produces an 80% yield of the methylaminodisulfonate.[180]

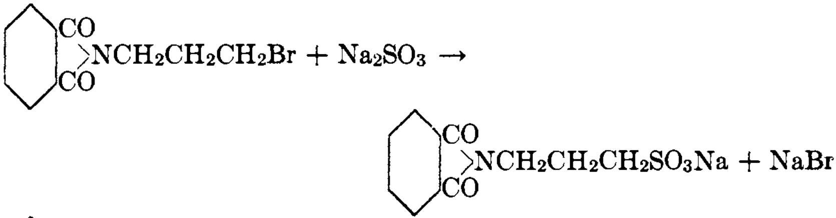
$$NaO_3SCH_2CH{=}CHCH_2SO_3Na + CH_3NH_2 \rightarrow NaO_3SCH_2CH_2CH(NHCH_3)CH_2SO_3Na$$

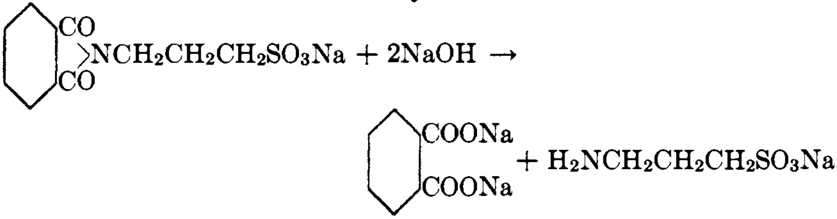
Several compounds are known in which the amino group is on the third carbon from the sulfonic acid. These likewise have been prepared by oxidation of cyclic sulfur-nitrogen rings.[190]



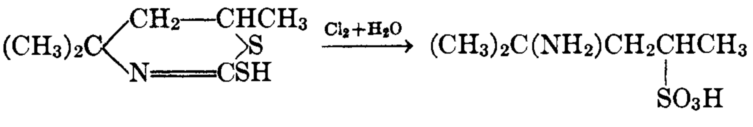


The methyl chloride addition product of this latter cyclic compound upon oxidation yields 3-methylaminopropane-1-sulfonic acid. 3-Aminopropane-1-sulfonic acid also has been synthesized by the hydrolysis of the phthalimido compound with alkali, and from the action of sulfurous acid upon trimethyleneimine.[145b]





A derivative of isohexane has been obtained as follows.[191]



4-Aminobutane-1-sulfonic acid has been obtained from the bromobutylphthalimide, whereas 5-aminopentane-1-sulfonic acid has been prepared as indicated by the equations.[145b]

$$C_6H_5CONH(CH_2)_5Cl \xrightarrow{Na_2SO_3} C_6H_5CONH(CH_2)_5SO_3Na \xrightarrow{NaOH} H_2N(CH_2)_5SO_3Na$$

An ω-aminodecanesulfonic acid has been produced by the action of hydrazoic acid upon the sulfoundecanoic acid resulting from sodium sulfite and the hydrogen bromide addition product of undecylenic acid.[145b] The basicity of the amino group increases as the number of methylenes between it and the sulfo group increases.

Hydroxyaminosulfonates and their derivatives are discussed under hydroxysulfonic acids.

Two types of sulfonic acids containing cyclic nitrogen may be included here. Sulfonic acids of piperidine and its homologs have been prepared by catalytic hydrogenation of pyridinesulfonic acids.[192]

Sulfonic acids containing the pyridone group may be prepared by condensing sodium chloromethanesulfonate and other similar compounds with pyridone or its alkali metal salts.[193]

$$C_5H_4ONNa + ClCH_2SO_3Na \rightarrow C_5H_4ONCH_2SO_3Na + NaCl$$

HYDROXYSULFONIC ACIDS

Aldehyde and Ketone Bisulfites. Only comparatively recently has it become clear that the bisulfite addition products of aldehydes and ketones are hydroxysulfonic acid derivatives rather than sulfites, and in many textbooks they are still not given a definite structure.

Practically all aliphatic aldehydes undergo reaction with metal bisulfites.[194] *n*-Butyl-*n*-hexylacetaldehyde reacts very slowly[195a] and the 1-aldehydo-2-methyl-5-isopropylcyclohexane addition product[195b] is decomposed even by cold water. Undecenal[196] gives a polymer rather than an addition product. Phenyldimethylacetaldehyde and diphenylethylacetaldehyde do not react.[197] It is not clear whether the lack of reaction is due to replacement of all three hydrogens by larger groups or whether the presence of an aromatic nucleus restricts the reaction. It has been mentioned that chloral[198] and bromal[199] do react. The addition products formed from sugars such as *d*-glucose and arabinose are much less stable than those from simple aldehydes.[200]

In general aromatic aldehydes readily add a bisulfite.[201] Exceptions are the aldehydes derived from thymol and carvacrol.[202]

Many ketones do not react with a bisulfite. With the exception of ethyl ketone which reacts slowly and to a limited extent [203] only ketones containing either a methyl group attached to the carbonyl [204] or having the carbonyl part of a ring system [205] of from four to seven or perhaps more carbon atoms combine appreciably. No systematic study of the effect of substituents in the ring of cyclic ketones upon bisulfite addition is available but some of the observations reported are interesting. Whereas menthone does not add sodium bisulfite [205g] the isomeric carvomenthone forms an unstable product.[205h] 3,5-Dimethylcyclohexanone and 3-methyl-5-isopropylcyclohexanone also react [205i] while the 2,3,6-trimethyl compound does not.[205j] The finding that 2-isopropylcyclohexanone and particularly 2-methyl-6-isopropylcyclohexanone react with sodium bisulfite [205k] is not in accord with the behavior of other similar compounds.

2-Methyl-4-isobutylcyclopentanone combines rapidly with bisulfite in the presence of alcohol [205l] as does a methyl-*tert*-butyl derivative [205s] but information is lacking for other substituted cyclopentanones. The unsaturated 3,5,5-trimethyl-2-cyclohexanone [205m] and isopulegone [205n] do not react with bisulfite while camphorphorone [205o] with sulfurous acid yields a stable sulfonic acid. Of the bicyclic ketones β-thujone (tanacetone) reacts [205p] and α-decalone [205q] gives an unstable addition product but carone [205r] and camphor are not affected.

Methyl ketones do not add bisulfite if the other group is large or highly branched [200] as in 3,4-dimethyl-2-pentanone. Reports in the literature concerning ketones that might be expected to be borderline cases do not give a clear idea of which compounds react and which ones do not because of probable differences in experimental procedures. For example methyl cyclopropyl ketone does not react with potassium bisulfite [205d] while both methyl and ethyl cyclobutyl ketones do combine with sodium bisulfite,[206b] the latter only in the presence of excess sulfur dioxide.

Ketones in which one or both groups are of an aromatic nature do not add bisulfites.[207] A variety of ethyl higher-alkyl ketones have been mentioned [208] as not reacting; such compounds as pentadecyl ketone [209] are also inert.

The formation of a bisulfite addition product has been utilized in the quantitative determination of a number of aldehydes. Formaldehyde may be determined by addition of excess bisulfite to its solution and titrating for the decrease in acid hydrogen [210] employing phenolphthalein as indicator. Another procedure depends upon the titration of unused bisulfite with iodine; [211] the addition product is not affected. Aldehydes and some ketones found in natural oils may be determined by measuring the decrease in volume of a sample of oil after it has been warmed with a sodium sulfite solution.[212] Most unsaturated ketones take up two moles of sodium bisulfite.[213] Camphor, menthone, and fenchone, however, do not react at all. The reaction with formaldehyde is more rapid than for any other aldehyde or ketone.

Several aspects of the reaction of aldehydes and ketones with bisulfites have been studied quantitatively. Wagner[214] has found that formaldehyde is converted to the addition product by two bimolecular processes, the first of which is twenty times as fast as the second.

$$HCHO + HSO_3^- \rightarrow HOCH_2SO_3^-$$

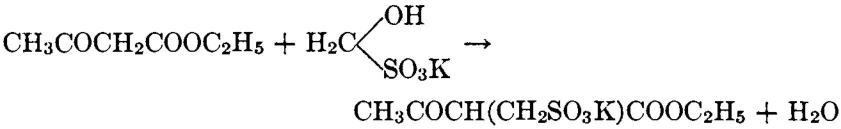
$$HCHO + SO_3^{--} + H_2O \rightarrow HOCH_2SO_3^- + OH^-$$

The reaction of benzaldehyde with sodium bisulfite has been investigated in detail.[215a] The reaction is reversible with the equilibrium favoring the addition product. The rate of dissociation is dependent upon the hydrogen-ion concentration; it is a minimum at *p*H 1.8 and very rapid in neutral solution. The equilibrium constant likewise varies with the *p*H, an alkaline solution favoring the decomposition products. In the *p*H range 3 to 13 the addition product results from interaction of the aldehyde and sulfite ion rather than bisulfite ion.

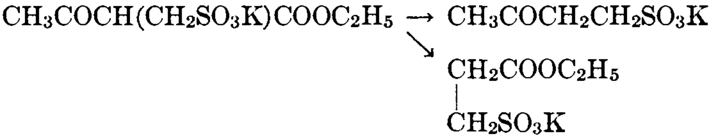
A study of the dissociation of the acetaldehyde addition product[215b] showed that at *p*H 6–8 it is small (less than 5%) while at *p*H 8–10.5 it increases to 50%. Above *p*H 12 practically complete dissociation occurs. If the addition compound is distilled with aqueous sodium bicarbonate all the aldehyde is liberated.

The structure of bisulfite compounds has been the subject of numerous investigations and much controversy. The preparation of a salt of "hydroxymethanesulfonic acid" presumably isomeric with the product obtained from formaldehyde and a bisulfite[216] and having different properties indicated that there was not a carbon-sulfur linkage in the addition compounds. More recently Raschig and Prahl[217] have shown that Müller's "hydroxymethanesulfonic acid" was actually acetone-1,3-disulfonic acid and his "hydroxydisulfonic acid" acetonetrisulfonic acid. The "hydroxymethanesulfonic acid" of Glimm[216b, 218] was found to be methyl hydrogen sulfate. Schroeter and co-workers[219] reported that the hydrolysis of diphenyl dimethylmethionate, $(CH_3)_2C(SO_3C_6H_5)_2$, gave the hydroxysulfonate $(CH_3)_2C(OH)SO_3Na$, which differed from the supposed addition product obtained from acetone. However, this addition product was shown to be actually the methyl ether of the hydroxysulfonate.[217]

The positive evidence for the hydroxysulfonate structure is now quite convincing. Raschig and Prahl[217] found that the condensation product of the formaldehyde addition product and ethyl acetoacetate is a true sulfonate.



$$\mathrm{CH_3COCH_2COOC_2H_5 + H_2C}\begin{matrix}\mathrm{OH}\\ \mathrm{SO_3K}\end{matrix} \rightarrow \mathrm{CH_3COCH(CH_2SO_3K)COOC_2H_5 + H_2O}$$



$$\mathrm{CH_3COCH(CH_2SO_3K)COOC_2H_5} \begin{array}{l} \rightarrow \mathrm{CH_3COCH_2CH_2SO_3K} \\ \searrow \begin{array}{l}\mathrm{CH_2COOC_2H_5}\\ \vert \\ \mathrm{CH_2SO_3K}\end{array}\end{array}$$

Backer and Mulder[220] showed that the amino compound derived from formaldehyde, sodium bisulfite, and ammonia is converted by nitrosyl chloride into sodium chloromethanesulfonic acid. An even more complete proof of structure has been supplied by Lauer and Langkammerer;[221] acetylation of the formaldehyde addition product was found to give an acetate identical with that obtained from potassium iodomethanesulfonate.

$$\mathrm{HOCH_2SO_3Na} \xrightarrow{\mathrm{NH_3}} \mathrm{H_2NCH_2SO_3Na} \xrightarrow{\mathrm{NOCl}} \mathrm{ClCH_2SO_3Na}$$

$$\mathrm{HOCH_2SO_3K} \rightarrow \mathrm{CH_3COOCH_2SO_3K} \leftarrow \mathrm{ICH_2SO_3K}$$

The physical properties of the hydroxysulfonates are in accord with their structure. Their absorption spectra contain a band at 4992 Å. characteristic of sulfonic acids[222] and differing from that of sulfites. The conductivity of solutions of the free acids is high, indicating the presence of typical sulfonic acids.[222, 223]

The second hydrogen is weakly acidic; the value of 7×10^{-10} for the dissociation constant was found for the benzaldehyde addition product. The addition of acetone to a sulfurous acid solution increases the conductivity appreciably[224a] even though the reaction is incomplete and the mixing of liquid sulfur dioxide with acetone or an aldehyde also leads to compound formation.[224b]

α-Hydroxysulfonic acids undergo a variety of reactions. They decompose in either acid or alkaline solutions[215, 225] giving the original carbonyl compounds. Sodium nitrite is a particularly good reagent for recovering aldehydes, the reaction occurring more rapidly than can be accounted for by the alkalinity alone.[226] Isovaleraldehyde was recovered in a 90% yield, a result at least as good as obtained with potassium carbonate solution. Reduction of potassium hydroxymethanesulfonate with zinc dust gives Rongalite, the corresponding hydroxysulfinate.[216b, 227a] As already mentioned, α-hydroxysulfonates are not oxidized by iodine in acid or neutral solution but reaction does occur in alkaline solution.[228]

$$HOCH_2SO_3Na + 2I_2 + 5NaOH \rightarrow HCOONa + NaHSO_4 + 4NaI + 3H_2O$$

Acetone bisulfite has been suggested for photographic solutions[229] because it is more stable than the sulfite alone.

Hydroxymethanesulfonic acid condenses with phenols,[227] a reaction analogous to that occurring with ethyl acetoacetate.

$$C_6H_5OH + HOCH_2SO_3Na \rightarrow HOC_6H_4CH_2SO_3Na + H_2O$$

The condensation of arsphenamine with formaldehyde and sodium bisulfite apparently leads to a compound which has an ether type of structure rather than new carbon-carbon linkages.[230] One of the amino groups also reacts in the formation of sulfarsphenamine. The reaction with ammonia and amines has been mentioned under α-aminosulfonic acids. Condensation likewise takes place with hydroxylamine and hydrazine.[217]

Replacement of the sulfo group by reaction with an alkali cyanide occurs readily and this is frequently the most convenient method for preparing hydroxynitriles[231] since it eliminates the handling of hydrogen cyanide.

$$RCHOHSO_3Na + KCN \rightarrow RCHOHCN + NaKSO_3$$

However, the anisaldehyde bisulfite gives a resinous mass from which only a compound $C_{25}H_{24}O_5N_2$ could be isolated.[232]

In a study of the physiological properties of hydroxysulfonates it was found that the most stable member of the series, that derived from formaldehyde, was least toxic and that the *d*-glucose derivative was of comparatively high activity. Apparently the compound most readily dissociated to sulfite is most toxic.[233]

The behavior of the bisulfite addition products of methyl glyoxime and its chlorine derivative, $CH_3COC(NOH)Cl$, toward various reagents has been described.[234]

Isethionic Acid: Preparation. The longest known and most investigated hydroxysulfonic acid is the first member of the β-hydroxyacid series, commonly known as isethionic acid. There has been a renewed interest in this compound of recent years because certain of its derivatives are detergents or wetting agents.

It was first recorded by Magnus[235, 236] that the action of sulfur trioxide upon ethyl alcohol or ether gives ethionic acid which can be hydrolyzed to isethionic acid.

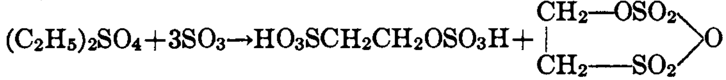
$$C_2H_5OH \xrightarrow{SO_3} C_2H_5OSO_3H \xrightarrow{SO_3} HO_3SCH_2CH_2OSO_3H$$

$$HO_3SCH_2CH_2OSO_3H + H_2O \rightarrow HO_3SCH_2CH_2OH + H_2SO_4$$

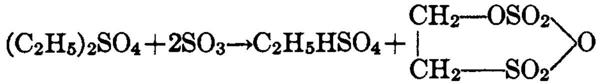
The sulfonation of barium ethyl sulfate produces similar results.[237] Liebig[238] was the first to obtain barium ethionate in a state of purity and report its composition correctly.

A comprehensive investigation of the action of sulfur trioxide upon ethyl ether[239] resulted in the isolation of a number of products and the formulation of the reaction in the following steps.

$$(C_2H_5)_2O+SO_3\ (\text{cold}) \rightarrow (C_2H_5)_2SO_4$$



$$(C_2H_5)_2SO_4+3SO_3 \rightarrow HO_3SCH_2CH_2OSO_3H + \begin{array}{l} CH_2\text{—}OSO_2\diagdown \\ | \qquad\qquad\quad\ \ \rangle O \\ CH_2\text{——}SO_2\diagup \end{array}$$

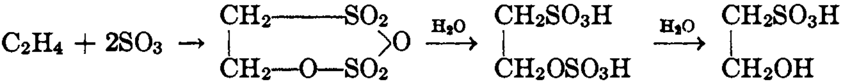


$$(C_2H_5)_2SO_4+2SO_3 \rightarrow C_2H_5HSO_4 + \begin{array}{l} CH_2\text{—}OSO_2\diagdown \\ | \qquad\qquad\quad\ \ \rangle O \\ CH_2\text{——}SO_2\diagup \end{array}$$

$$HO_3SCH_2CH_2OSO_3H+2SO_3 \rightarrow CH_2(SO_3H)_2+2SO_2+CO_2+H_2O$$

From 1.3 kg. of ether and 1.5 kg. of sulfur trioxide, 600 g. of ethyl sulfate was obtained. By increasing the sulfur trioxide used to 2.1 kg., 750 g. of isethionic acid was formed. From 100 g. of ethyl sulfate and 88 g. of sulfur trioxide, 5.4 g. of barium methionate, $CH_2(SO_3)_2Ba$, also was recovered. The best method found for obtaining isethionic acid was to pass gaseous sulfur trioxide into dry ether at 0°, treat the reaction mixture with water to recover the ethyl sulfate (which may be further sulfonated) and hydrolyze the ethionic acid by boiling the solution.

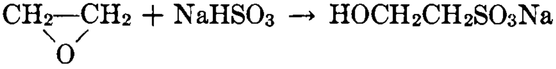
Sulfur trioxide acts readily[240] upon ethylene with formation of white crystals of carbyl sulfate that hydrolyze first to ethionic acid and



$$C_2H_4 + 2SO_3 \rightarrow \begin{array}{l} CH_2\text{———}SO_2 \\ | \qquad\qquad\quad \rangle O \\ CH_2\text{—}O\text{—}SO_2 \end{array} \xrightarrow{H_2O} \begin{array}{l} CH_2SO_3H \\ | \\ CH_2OSO_3H \end{array} \xrightarrow{H_2O} \begin{array}{l} CH_2SO_3H \\ | \\ CH_2OH \end{array}$$

finally to isethionic acid. Carbyl sulfate has also been obtained as a primary product[241] in the action of sulfur trioxide upon ethyl alcohol but not from ether and this reagent. Sulfur dioxide has been patented as a solvent for carrying out sulfonations of olefins and alcohols in the preparation of isethionic acid and its homologs.[242] Although chlorosulfonic acid adds to ethylene to give chiefly ethyl chlorosulfonate, ethionic acid is also found[243] in small amount in the hydrolysis product owing to further sulfonation of the ethyl chlorosulfonate.

Sodium isethionate has also been obtained by the reaction of sodium sulfite upon ethylene chlorohydrin,[244] and from ethylene oxide reacting with the bisulfite.[145b, 245]



Isethionic Acid: Properties and Reactions. Although the structure of isethionic acid was deduced [246] from its relationship to taurine, the first proof of its atomic arrangement was the oxidation to sulfoacetic acid.[247] Heating ammonium isethionate [248] results in the formation of the ether rather than the amide. Other salts were found to behave similarly.

$$2HOCH_2CH_2SO_3NH_4 \rightarrow O(CH_2CH_2SO_3NH_4)_2 + H_2O$$

This ether also has been prepared by oxidation of the dithiol and from β-chloroethyl ether and ammonium sulfite.[249a] The disulfonamide reacts with formaldehyde to give a resinous material.[249b]

Potassium isethionate with phosphorus pentachloride forms chloroethanesulfonyl chloride [250a] whereas the acetate [250b] reacts only at the sulfo group.

$$CH_3COOCH_2CH_2SO_3K + PCl_5 \rightarrow CH_3COOCH_2CH_2SO_2Cl + KCl + POCl_3$$

It is possible to replace the hydroxyl group by chlorine by heating isethionic acid with hydrochloric acid.[251]

Esters of isethionic acid suitable for use as detergents [178c] may be made by action of an acid chloride upon the hydroxy acid or from 2-chloroethanesulfonic acid.[252a,c,d] Esters of alkylbenzoic acids are

$$C_{17}H_{33}COCl + HOCH_2CH_2SO_3Na \rightarrow C_{17}H_{33}COOCH_2CH_2SO_3Na + HCl$$

$$RCOONa + ClCH_2CH_2SO_3Na \rightarrow RCOOCH_2CH_2SO_3Na + NaCl$$

formed by heating the sulfonic acid with the free benzoic acid.[178d, 252b]

$$RC_6H_4COOH + HOCH_2CH_2SO_3H \rightarrow RC_6H_4COOCH_2CH_2SO_3H + H_2O$$

More recently a great variety of ethers of isethionic acid have been prepared and suggested as having detergent activity. These may be obtained by action of a sodium alcoholate or phenolate upon a chloroethanesulfonate,[253a,b,e,f] from sodium sulfite and a chloro ether,[253c,g] or even by heating an alcohol such as octadecyl alcohol with the isethionic

$$ArOCH_2CH_2OCH_2CH_2Cl + Na_2SO_3 \rightarrow ArOCH_2CH_2OCH_2CH_2SO_3Na + NaCl$$

acid.[253d]

$$C_{18}H_{37}OH + HOCH_2CH_2SO_3H \rightarrow C_{18}H_{37}OCH_2CH_2SO_3H + H_2O$$

By heating together isethionic acid and an aminobenzoic acid or ester[254] at 140° there is presumably formed the sulfonamide of the acid.

$$HOCH_2CH_2SO_3H + NH_2C_6H_4COOC_2H_5 \rightarrow HOCH_2CH_2SO_2NHC_6H_4COOH + C_2H_5OH$$

The product is stable to hydrochloric acid but is hydrolyzed by alkali. This behavior is more characteristic of an ester of the carboxyl group, suggesting that the compound is really a benzoate, particularly since benzoic acid also reacts.

$$HOCH_2CH_2SO_3H + ArCOOH \rightarrow ArCOOCH_2CH_2SO_3H + H_2O$$

It is not possible to esterify isethionic acid by heating with alcohol in the presence of hydrogen chloride and the yield is minute when the silver salt is heated with ethyl iodide.

1-Bromo-2-hydroxyethane-1-sulfonic acid has been obtained[255] by reaction of the bromoethylenesulfonic acid with water. Sodium amalgam reduces it to isethionic acid. The action of barium permanganate results in oxidation to bromosulfoacetic acid, silver oxide yields glycolic acid, and nitric acid gives oxalic acid as the final product. Heating the potassium salt to 225° produces the ether as with salts of isethionic acid.

$$CH_2{=}CBrSO_3H + H_2O \rightarrow CH_2OH{-}CHBrSO_3H$$

$$2HOCH_2CHBrSO_3K \rightarrow O(CH_2CHBrSO_3K)_2 + H_2O$$

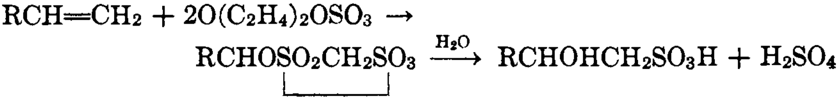
With acetic anhydride the acetate results. By treating bromoethylenesulfonic acid with sulfuric acid at 75° bromoethionic acid is formed. This readily undergoes hydrolysis.

$$CH_2{=}CBrSO_3H + H_2SO_4 \rightarrow HO_3SOCH_2CHBrSO_3H \xrightarrow{H_2O} HOCH_2CHBrSO_3H$$

Miscellaneous Hydroxysulfonic Acids. A number of homologs and analogs of isethionic acid are known.[256b] The reaction of ammonium sulfite with isobutylene bromohydrin[256a] is normal giving the 2-methyl-2-hydroxypropane-1-sulfonate.

The reaction of olefins of higher molecular weight than ethylene with sulfur trioxide is complicated by side reactions, although this reaction has been mentioned in the patent literature.[240d] Products from olefins and pyrosulfuryl chloride[256c] also have been described.

Olefins with the double bond at the end of the chain react with dioxane sulfotrioxide to give higher homologs of carbyl sulfate which hydrolyze readily to the hydroxy sulfonic acids.[257]

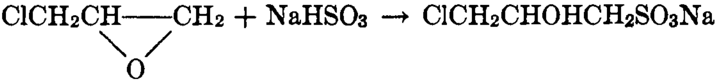


$$\mathrm{RCH{=}CH_2 + 2O(C_2H_4)_2OSO_3 \rightarrow RCHOSO_2CH_2SO_3 \xrightarrow{H_2O} RCHOHCH_2SO_3H + H_2SO_4}$$

Sulfonation of *n*-propyl alcohol with sulfur trioxide,[258] reduction of sulfopropionaldehyde,[259] and addition of potassium bisulfite to allyl alcohol[12d] all give 3-hydroxypropane-1-sulfonic acid or a salt. 4-Bromobutane-1-sulfonic acid has been hydrolyzed to the hydroxy acid[260a] and 6-hydroxyhexane-1-sulfonic acid[260b] has been made from hexamethylene chlorohydrin. Esters of this, like those of isethionic acid, are surface-active agents. Esters of 1-hydroxybutane-2-sulfonic acid[60a] have also been mentioned, as have derivatives of sodium 2-hydroxycyclohexane-1-sulfonate.[261] The hydroxy acid is claimed to result from the reaction of sulfuric acid with cyclohexene in the presence of acetic acid and acetic anhydride.[262a] The sulfonic acid structure was assigned because of the resistance to hydrolysis of the product in alkaline solution. The reaction of sulfur dioxide and chlorine with olefins, followed by hydrolysis, also gives hydroxysulfonic acids.[262g]

A product which has the composition of an octanesultone,[262b] presumably that derived from 3-hydroxyoctane-1-sulfonic acid, has been isolated from the residues obtained by treating petroleum with sulfuric acid. However, attempts to convert the sulfonic acid obtained from γ-hydroxyoctyl iodide into this sultone have not been successful and its structure must be regarded as uncertain.[262c] A sultone has also been obtained by the action of sulfur trioxide in acetic acid[262d] or sulfonic acid in acetic anhydride[262e] upon camphene. Since the sultone was also obtained from 2-hydroxycamphane-π-sulfonic acid the sulfonation involves a rearrangement. The sulfonation of nitrocamphenes[262f] gives similar results.

Epichlorohydrin combines with sodium bisulfite readily[263] at 100° with formation of a sulfonic acid which has also been obtained from



$$\mathrm{ClCH_2CH{-}CH_2\,(O) + NaHSO_3 \rightarrow ClCH_2CHOHCH_2SO_3Na}$$

sodium sulfite and glycerol α-dichlorohydrin,[264a] from the sulfonation of allyl chloride,[264c] and from the oxidation of the chlorohydroxythiol.[264b] The corresponding disulfonic acid results by using an excess of alkali sulfite [205] with the dichlorohydrin.

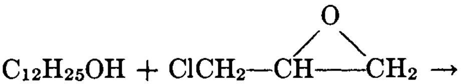
The reaction of 3-chloro-2-hydroxypropane-1-sulfonic acid with nitrogen bases yields wetting agents.[266a]

$$ClCH_2CHOHCH_2SO_3Na + C_{12}H_{25}N(CH_3)_2 \rightarrow C_{12}H_{25}\overset{+}{N}(CH_3)_2CH_2CHOHCH_2SO_3^- + NaCl$$

Acyl derivatives of 3-amino-2-methoxypropane-1-sulfonic acid have likewise been mentioned in this connection.[266b] The sulfonation of higher chlorinated olefins has been described.[266d]

Unsaturated alcohols related to the terpenes add sodium bisulfite readily with the formation of water soluble sodium sulfonates.[267] Cinnamyl alcohol reacts somewhat less easily. The esters of these alcohols do not react in this way. This may possibly be due to the smaller solubility of the esters in the sodium bisulfite solution.

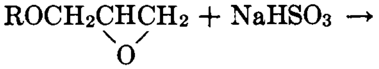
Ethers and esters of dihydroxy acids are mentioned in the patent literature. Sulfonation of unsaturated ethers [268] presumably gives hydroxy sulfonates as does the reaction of sodium sulfite with the ethers obtained from epichlorohydrin [269] and alcohols or phenols.



$$C_{12}H_{25}OH + ClCH_2\text{—}\overbrace{CH\text{——}CH_2}^{O} \rightarrow$$

$$C_{12}H_{25}OCH_2CHOHCH_2Cl \xrightarrow{Na_2SO_3} C_{12}H_{25}OCH_2CHOHCH_2SO_3Na$$

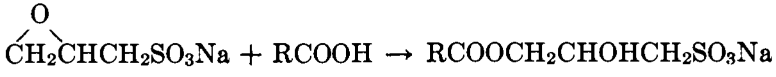
Ethers have also been obtained from the oxide [270a] and diesters [270c] have been made from the bromohydrin.



$$ROCH_2\underbrace{CHCH_2}_{O} + NaHSO_3 \rightarrow ROCH_2CHOHCH_2SO_3Na$$

$$CH_2OHCHOHCH_2Br \rightarrow RCOOCH_2(RCOO)CHCH_2Br \rightarrow RCOOCH_2(RCOO)CHCH_2SO_3Na$$

Sodium 2,3-epoxypropane-1-sulfonate reacts with fatty acids to give mono esters.[220c] Esters have also been obtained by heating the di-



$$\overbrace{CH_2CH}^{O}CH_2SO_3Na + RCOOH \rightarrow RCOOCH_2CHOHCH_2SO_3Na$$

hydroxy sulfonate with a variety of acids.[252b] Esters obtained from 1,3-dihydroxypropane-2-sulfonic acid have also been described.[270b] The sulfonation of the acetates of unsaturated hydroxy compounds may yield sulfonic acids.[270d]

As is pointed out later, the sulfonation of unsaturated fats and oils gives sulfonic acids that probably contain hydroxyl groups, but their structures are uncertain.

ALDEHYDE AND KETONE SULFONIC ACIDS*

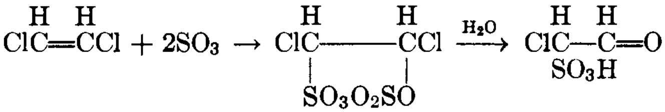
The preparation of a considerable number of sulfonic acids has been accomplished through the addition of an alkali bisulfite to an unsaturated aldehyde or ketone in which the double bond is conjugated with the carbonyl group. Direct sulfonation of a ketone has been practical chiefly for the camphorsulfonic acids, and the replacement of halogen by sulfo groups has been tried in only a few instances.

Aldehydesulfonic Acids. Sulfoacetaldehyde results from hydrolysis of an amide of formylmethionic acid with hydrochloric acid,[271] and possibly from the treatment of potassium isethionate with fuming sulfuric acid.[237,272] The bisulfite addition product of sulfoacetaldehyde is probably formed in the reaction of 1,1,2-trichloro- or tribromoethane with an alkali sulfite.[273]

$$\mathrm{OCHCH[SO_2N(C_2H_5)C_6H_5]_2 + 3H_2O \rightarrow OCHCH_2SO_3H + H_2SO_4 + 2C_6H_5NHC_2H_5}$$

$$\mathrm{BrCH_2CHBr_2 + 3(NH_4)_2SO_3 + H_2O \rightarrow NH_4O_3SCH_2CHOHSO_3NH_4 + 3NH_4Br + NH_4HSO_3}$$

Chlorosulfoacetaldehyde results from the action of fuming sulfuric acid upon acetylene dichloride.[274]



$$\mathrm{Cl\overset{H}{C}{=}\overset{H}{C}Cl + 2SO_3 \rightarrow \begin{array}{c} Cl\overset{H}{\underset{|}{C}}\text{———}\overset{H}{\underset{|}{C}}Cl \\ SO_3O_2SO \end{array} \xrightarrow{H_2O} Cl\overset{H}{\underset{SO_3H}{C}}{-}\overset{H}{C}{=}O}$$

The sulfonic acid is hydrolyzed by 60% sulfuric acid to chloroacetaldehyde and is oxidized by oxygen in alkaline solution or by hydrogen peroxide to chlorosulfoacetic acid.

Acetaldehydedisulfonic acid and its chloro and bromo derivatives are mentioned in connection with the preparation of methionic acid (see p. 157). β-Sulfopropionaldehyde [258,275], β-sulfobutyraldehyde,[275,276] and α-methyl-β-sulfovaleraldehyde [277] have been obtained from the corresponding unsaturated aldehydes. A disulfopropionaldehyde is mentioned under alkylmethionic acids. The addition of sodium bisulfite to citronellal,[278] in which the double bond is not conjugated with the carbonyl group, gives the normal aldehyde addition product in the absence of excess sulfur dioxide when the reaction is carried out at 0°. In the presence of some sodium sulfite the sulfonic acid is formed from which the aldehyde cannot be recovered, dilute alkali

---

* See under "Methionic Acid" for disulfonic acids containing the carbonyl group.

$$(CH_3)_2C{=}CHCH_2CH_2{-}CH(CH_3)CH_2CHO + 2NaHSO_3 \rightarrow$$
$$(CH_3)_2C(SO_3Na)(CH_2)_3CH(CH_3)CH_2CHOHSO_3Na$$

giving the sulfodihydrocitronellal.

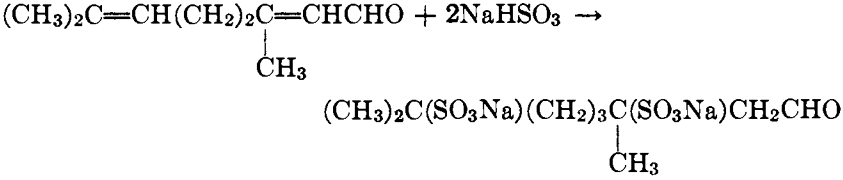
The reaction of sodium bisulfite with citral [279] is more complex because of the presence of two olefinic linkages, one of these being conjugated with the aldehyde group. Here again the normal bisulfite addition compound can be obtained under specific conditions, the presence of an acid such as acetic being necessary. By carrying out the reaction with a mixture of sodium sulfite and sodium bicarbonate an addition product is obtained containing two molecules of bisulfite which is decomposed by dilute alkali into citral. The structure of this compound is not certain but it seems probable that it is as shown, since this would account for its reactions with alkali. It gives a semi-

$$(CH_2)_2C{=}CHCH_2CH_2C(CH_3)(SO_3Na)CHCHOHSO_3Na$$

carbazone which was interpreted to mean the presence of a free aldehyde group. This reaction might come through rearrangement to the isomeric disulfonic acid, through dissociation of the aldehyde addition product, or if semi-carbazide acts like ammonia or hydrazine the reaction might also be formulated in the following fashion.

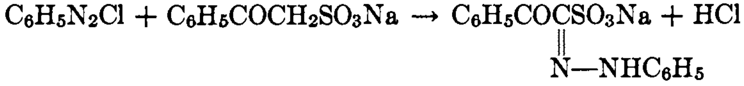
$$RCHOHSO_3Na + NH_2NHCONH_2 \rightarrow$$
$$RCH(NHNHCONH_2)SO_3Na + H_2O$$

By acid treatment the "labile" addition product is converted into an isomeric compound, one that also results by addition of two moles of sodium bisulfite to citral in acid solution. Further investigation is necessary to elucidate completely the nature of these reaction products.



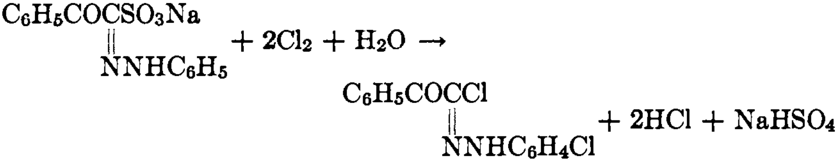
$$(CH_3)_2C{=}CH(CH_2)_2\underset{\substack{|\\ CH_3}}{C}{=}CHCHO + 2NaHSO_3 \rightarrow$$
$$(CH_3)_2C(SO_3Na)(CH_2)_3\underset{\substack{|\\ CH_3}}{C}(SO_3Na)CH_2CHO$$

Ketonesulfonic Acids. Potassium acetonesulfonate is obtained by heating chloroacetone with potassium sulfite solution.[280] It is unaffected by warming with dilute mineral acids but it is cleaved by alkali. The free acid was obtained only as a syrup. By treating phenacyl bromide with sodium sulfite in aqueous alcohol solution a 90% yield of sodium benzoylmethanesulfonate results.[281] When this is warmed with sodium hydroxide, cleavage to sodium benzoate occurs.[282] It reacts with a diazonium chloride to give the arylhydrazone.



$$C_6H_5N_2Cl + C_6H_5COCH_2SO_3Na \rightarrow \begin{array}{c} C_6H_5COCSO_3Na \\ \| \\ N{-}NHC_6H_5 \end{array} + HCl$$

Chlorine removes the sulfo group and substitutes in the ring attached to nitrogen.



$$\begin{array}{l} C_6H_5COCSO_3Na \\ \| \\ NNHC_6H_5 \end{array} + 2Cl_2 + H_2O \rightarrow \begin{array}{l} C_6H_5COCCl \\ \| \\ NNHC_6H_4Cl \end{array} + 2HCl + NaHSO_4$$

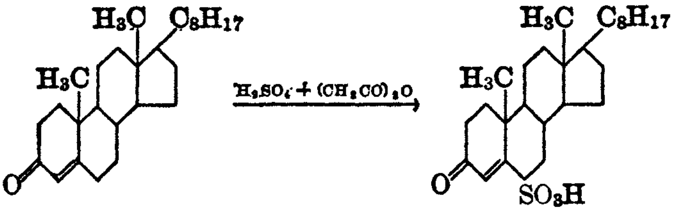
Practically all unsaturated ketones add sodium bisulfite at the carbon-carbon double bond as well as at the ketone group. As examples, allylacetone,[283] mesityl oxide,[284] phorone, carvone,[285] 2-methyl-2-cyclopentenone-1,[286] and a large number of unsaturated compounds containing aryl groups [287] may be cited. Pulegone gives the "normal" addition product with sodium bisulfite,[288] but with sulfur dioxide in alcohol at 20° a sulfonic acid results.[289] The salts of this acid which contain non-poisonous metals are physiologically inactive. Sabinol is converted into its sulfonic acid at 0° in a similar manner. On heating with potassium hydroxide, this is changed into an alcohol which after reduction and then oxidation gives thujone. Its structure is, however, not entirely certain.

Some of the sulfonic acids produced in this fashion have been shown to decompose with alkali [284b] with formation of the original or an isomeric unsaturated ketone.

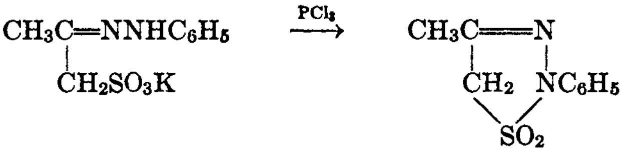
The sulfonation of pulegone with sulfuric acid in acetic anhydride [290] yields a cyclic sulfonate that undergoes hydrolysis with hot sodium hydroxide.

$$C_{10}H_{16}O + H_2SO_4 \xrightarrow{(CH_3CO)_2O} C_{10}H_{14}SO_3 + [2H_2O]$$

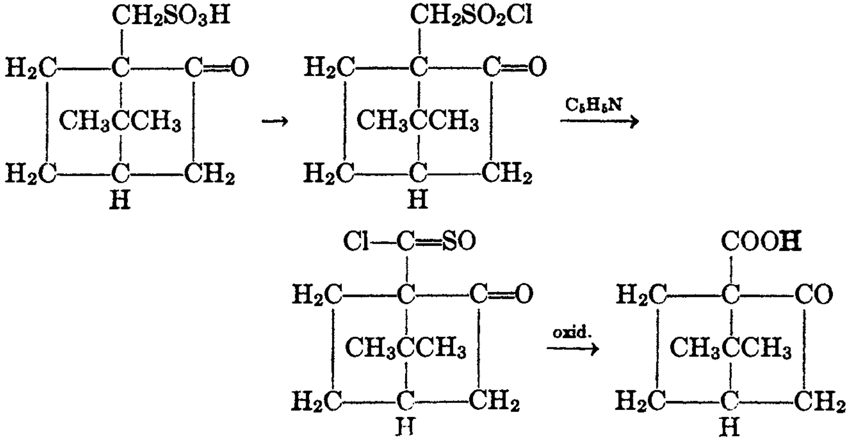
A number of higher-molecular-weight sulfonic acids obtained from ketones have been found to have wetting or detergent properties.[291,292] Such compounds are those from oleone and palmitone,[291a] alkyl aryl ketones,[292] and cholestenone.[293] In this last case it is surprising that substitution rather than addition occurs.



There is some analogy between the reaction of β-ketosulfonic[294] and carboxylic acids; acetonesulfonic acid when heated with concentrated sulfuric or phosphoric acid loses sulfur dioxide. To be strictly analogous this should be sulfur trioxide, but the reaction which does occur indicates a reactivity of the sulfo group above that of an unsubstituted acid. The phenylhydrazone with phosphorus trichloride forms a cyclic compound.



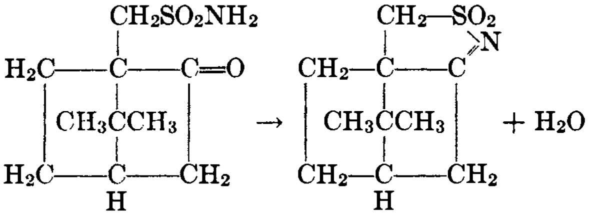
Camphorsulfonic Acids. Sulfonic acids derived from *d*-camphor and α-bromo-*d*-camphor have been studied extensively because of their usefulness in the resolution of basic compounds. Reychler[295] found it possible to sulfonate camphor in acetic anhydride solution with sulfuric acid to form a crystalline camphorsulfonic acid, m.p. 193–195°. The structure of this acid has been thoroughly[296] investigated, the 10- or β-position of the sulfo group being most convincingly shown by the following reactions.



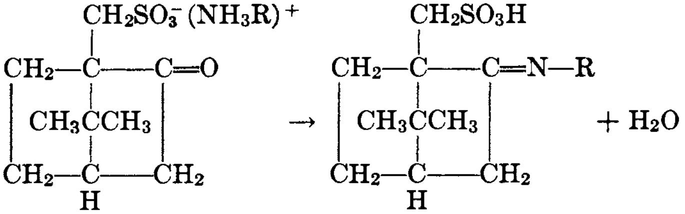
The ketopinic acid structure is known from other reactions.

The corresponding sulfo derivatives of *l*-camphor and *dl*-camphor[297] have also been prepared.

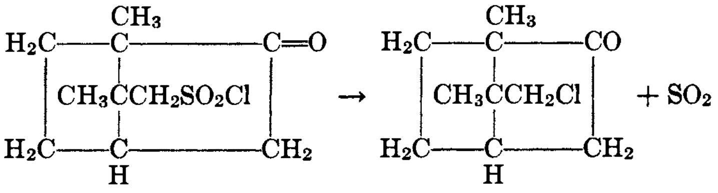
Fusion of the *d*-camphor-β-sulfonic acid with potassium hydroxide[298] converts it into α-campholenic acid. By reduction with sodium in alcohol two isomeric hydroxysulfonic acids result,[299] one of which can be dehydrated to the sultone. *d*-Camphor-β-sulfonamide under the influence of a trace of alkali is converted into a cyclic compound as follows.



In an examination of the anomalous mutarotation of primary amine salts of 10-camphorsulfonic acid it was found that these gradually lost water in anhydrous solvents with the formation of ketimines.[300]



Sulfonation of *d*-camphor with chlorosulfonic acid or fuming sulfuric acid[301] gives a racemic sulfo compound, *dl*-camphor-π (or 8-)-sulfonic acid. The optically active forms have been obtained[302] by reduction of the corresponding bromosulfonic acids, and by resolution[303] of the inactive compound. Heating *dl*-camphor-π-sulfonyl chloride to 190° eliminates sulfur dioxide.[302a]



Conversion of the sulfonyl chloride to the sulfoxide followed by oxidation[304] gives the corresponding carboxylic acid as with the β-sulfonyl chloride.

Another *d*-camphorsulfonic acid has been obtained by the sulfonating action of methyl chlorosulfonate [305] followed by hydrolysis. Oxidation gives camphoric acid so this must be the α- or 3-sulfonic acid. The methyl ester is soluble in alkali owing to the acidity of the hydrogen attached to carbon between the keto and sulfonate groupings. Heating the sulfonic acid to 200° with aniline regenerates *d*-camphor and forms sulfanilic acid.

Sulfonation of the α-chloro or α-bromo-*d*-camphor forms the corresponding β-sulfonic acids [306] or the π-sulfonic acids,[301,307] depending upon the sulfonating conditions used. The π-compounds have been obtained in a pure state through the hydroxyhydrindamine salts. They show mutarotation in alkaline solution. Their sulfonyl chlorides are isomorphous and by mixing *d*-chlorocamphorsulfonyl chloride with *l*-bromocamphorsulfonyl chloride there is formed an "active racemate." [308] The sulfonamides behave in an analogous manner. Oxidation of these sulfonic acids converts them into a camphoric acid derivative.[309]

The sulfonation of α-bromo-*l*-camphor [310] and of α-bromo-*dl*-camphor [311] has been investigated. The sulfonic acid obtained in the latter case has also been obtained by mixing the active forms.[312] The resolution of the *dl* compound with α-*p*-tolylethylamine [311] is readily carried out. *dl*,2-Dihydropapavarine has also been utilized [313] for this purpose.

β-Bromocamphor when sulfonated at 30–40° with sulfuric acid and acetic anhydride gives a 15–20% yield of the α-sulfonic acid.[314] The corresponding sulfonyl bromide decomposes in boiling xylene to give a mixture of α,β- and α′,β-dibromocamphor. Bromination of the sulfonamide forms α,β-dibromocamphorsulfonamide whereas the acetyl derivative yields α′,β-dibromocamphor-α-sulfonamide.

ALIPHATIC SULFOCARBOXYLIC ACIDS

The aliphatic α-sulfocarboxylic acids have been intensively investigated during the last few years. Less information is available concerning the β- and γ-sulfoacids but a number of them have been prepared.

SULFOMONOCARBOXYLIC ACIDS

General Methods of Preparation. The application of the reaction between a halogen compound and a metal sulfite to the preparation of a sulfocarboxylic acid was apparently first made by Strecker [315] in preparing sulfoacetic acid. This reaction has been studied for a large number of halogenated fatty acids by Backer and Van Mels,[310] who investigated the kinetics of the reaction. In Table VI are given the reaction velocity constants for the potassium salts of the acids with potassium sulfite. K is for a bimolecular reaction. The results obtained when sodium or ammonium salts were used are not greatly different from those given in the table, the values of K being only slightly lower.

For the compounds listed in Table VI, the side reactions are negligible for the experimental conditions used. With other halogen compounds these may become important. For *d*-α-bromoisobutyric acid, hydrolysis proceeds much more rapidly than sulfonic acid formation. Bromomalonic acid is reduced, and ethylbromomalonic acid is both hydrolyzed and reduced. In the case of bromosuccinic acid the formation of fumaric and maleic acids, hydrolysis to malic acid, and formation of sulfosuccinic acid all occur simultaneously.

TABLE VI

HALOGENATED ACIDS AND POTASSIUM SULFITE

ACID	K AT 25°	ACID	K AT 25°
$ClCH_2COOH$	0.00461	$ClCH_2CH_2COOH$	0.000532
$BrCH_2COOH$	0.454	$BrCH_2CH_2COOH$	0.0205
ICH_2COOH	0.793	ICH_2CH_2COOH	0.0326
$Cl_2CHCOOH$	0.000117	$CH_3CH_2CHBrCOOH$	0.0045
$ClBrCHCOOH$	0.00331	$CH_3(CH_2)_2CHBrCOOH$	0.00234
$CH_3CHClCOOH$	0.000160	$(CH_3)_2CHCHBrCOOH$	0.000037
$CH_3CHBrCOOH$	0.0134	$CH_3(CH_2)_3CHBrCOOH$	0.0015
$CH_3CHICOOH$	0.0252		

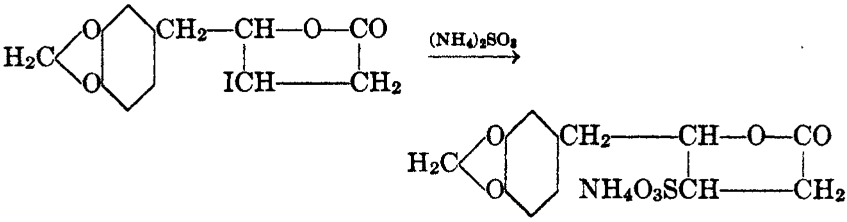
Chlorosulfoacetic acid does not react in any way during two weeks' standing, while the bromo compound is reduced to sulfoacetic acid. With dibromoacetic and α,α-dibromopropionic acids reduction and sulfonic acid formation occur together. The α,β-dibromopropionic acid gives $K = 0.0032$, which is markedly less than either of the corresponding monobromo compounds. Which of the two bromines reacts the more rapidly was not determined.

The esters of the halogenated acids react much more rapidly with potassium sulfite[317a] than do the salts of the acids. For these reactions it is advantageous to use 40% ethyl alcohol as a solvent.

The reaction of sodium thiosulfate with the salts of halogenated acids has also been investigated.[263] The thiosulfonates formed are readily oxidized to the sulfonic acids.

A thorough discussion of the various results obtained in the preceding work has been published.[317b] The conclusions drawn which are of interest from the standpoint of the preparation of the sulfoacids are: (1) a bromo acid should be used; (2) with a chloro acid the addition of potassium iodide to the reaction mixture accelerates the reaction; (3) a low temperature and high concentrations of the reactants are desirable; (4) the use of 40% alcohol as a solvent speeds up the reaction to a marked degree as compared with the results in aqueous solution; (5) secondary reactions are reduced if an ester is used instead of the salt of the acid. With a salt of the acid, addition of the corresponding alkali salt also reduces the importance of side reactions by increasing the rapidity of sulfonate formation.

The preparation of α-sulfo derivatives of the higher fatty acids such as lauric acid by treatment of the bromo compounds with an alkali sulfite in concentrated aqueous solution has been patented.[818] This reaction has also been applied[819] to the halogen acids obtained from oleic or ricinoleic acids by addition of halogen to the ethylenic linkage. The reaction of ammonium sulfite with ammonium α-bromophenylacetate[820a] at room temperature gives a 70% yield of the sulfo acid isolated as the barium salt. In addition, an appreciable quantity of mandelic acid is produced. At higher temperatures the hydrolysis reaction becomes predominant. The corresponding α-chloro acid gives only a 35% yield while the use of ethyl α-bromophenylacetate produces a practically theoretical yield of the sulfo compound. These results are in general accord with the results of the kinetic measurements already discussed. The action of ammonium sulfite upon an iodolactone related to piperic acid proceeds normally.[820b]



Several α-sulfoacyl derivatives of urea and of guanidine have been prepared by the action of an alkali sulfite upon a corresponding chloro or bromo compound.[821]

The sulfonation of fatty acids with various reagents has received much attention. The action of sulfuric acid[822] or chlorosulfonic acid[823] upon acetic acid leads to the formation of sulfoacetic acid. By the use of sulfur trioxide[824] it is possible to prepare the intermediate mixed anhydride which is stable enough to be isolated at 0° or below.

Sodium acetylsulfate is precipitated by sodium acetate from the acetic acid solution of the anhydride.

$$CH_3COOH + SO_3 \rightarrow CH_3COOSO_3H$$

$$CH_3COOSO_3H + CH_3COONa \rightarrow CH_3COOSO_3Na + CH_3COOH$$

Acetylsulfuric acid has also been prepared by the action of acetic anhydride with sulfuric acid [325] and at a higher temperature from acetyl chloride and sulfuric acid.[325]

$$H_2SO_4 + CH_3COCl \rightarrow CH_3COOSO_3H + HCl$$

Heating the acetylsulfuric acid gives rise to sulfoacetic acid and various by-products whereas the sodium salt [326] either alone or with sodium acetate yields acetic anhydride.

$$2CH_3COOSO_3Na \rightarrow (CH_3CO)_2O + Na_2S_2O_7$$

$$CH_3COOSO_3Na + CH_3COONa \rightarrow (CH_3CO)_2O + Na_2SO_4$$

In the preparation of sulfoacetic acid from acetyl chloride and silver sulfate [327] the intermediate silver acetylsulfate must undergo a rearrangement analogous to that of the free acid.

Treatment of propionic acid with sulfur trioxide or propionic anhydride with sulfuric acid gives the mixed anhydride; [328] this rearranges to the α-sulfonic acid when heated, but because of side reactions the yield is only 55%. Oleum reacts directly with propionic acid to give a 75% yield of the same compound. This indicates that the sulfonic acid may be formed in other ways than by rearrangement of the mixed anhydride.

n-Butyric acid,[325a, 329] isobutyric acid,[330] *n*-valeric acid,[331] isovaleric acid,[332] methylethylacetic acid,[333] and methyl-*n*-propylacetic acid [334a] have all been converted into α-sulfonic acids by direct sulfonation. Better yields of the α-sulfovaleric acid were obtained by sulfonation of *n*-propylmalonic acid and loss of carbon dioxide. A reaction [334c] between stearic acid and sulfuric acid may produce a sulfonic acid. The sulfonation method is not applicable in the preparation of aryl substituted acids such as α-sulfophenylacetic acid [267] as sulfonation of the aromatic nucleus occurs more easily than that of the side chain. Camphoric acid undergoes complex changes when heated with sulfuric acid to yield sulfocamphyllic acid.[334b]

A study of the action of chlorosulfonic acid with some acyl chlorides has yielded interesting results. The reaction with acetyl chloride [335] takes place even at a temperature of −10°, acetyl chlorosulfonate being the first product. Above 45° this rearranges to sulfoacetyl chloride.

$$CH_3COCl + ClSO_3H \rightarrow CH_3COOSO_2Cl + HCl$$

$$CH_3COOSO_2Cl \rightarrow CH_2(SO_3H)COCl$$

Above 60° with more chlorosulfonic acid further sulfonation occurs. The sulfonyl chloride was not isolated as such but as methanedisulfonic

$$HO_3SCH_2COCl + ClSO_3H \rightarrow HO_3SCH_2SO_2Cl + CO_2 + HCl$$

acid. About 3% of a complex pyrone derivative was also found in the reaction mixture.

In a similar study of the sulfonation of propionyl chloride [336] some sulfopropionic acid was isolated but a considerable amount of condensation product was formed even at room temperature. In the reaction of butyryl chloride with chlorosulfonic acid [337] none of the sulfonic acid was formed; carbon monoxide was evolved during the reaction and *n*-propyl ketone was isolated as one of the reaction products.

Sulfonation of the acid chlorides of higher acids including naphthenic acids at temperatures below 40° gives products stable to hard water that may be used as washing and emulsifying agents.[338] The condensation of sulfonic acids obtained from acid chlorides with phenol has also been suggested as a source of wetting agents.[339a] The sulfonation of complex amides of stearic acid [339b] probably occurs in the stearyl group.

Sulfonation of chloroacetic acid with chlorosulfonic acid [340] at 140–150° yields chlorosulfoacetic acid with chloromethanedisulfonic acid as a by-prdouct. Bromosulfoacetic acid has been prepared in 70% yield by the action of sulfur trioxide [341] upon bromoacetic acid.

$$BrCH_2COOH + SO_3 \rightarrow BrCH_2COOSO_3H \rightarrow BrCH(SO_3H)COOH$$

Sulfonation of α-chloro-, or α-bromopropionic acid [342] gives only 25–30% yields of the sulfonic acid, halogenation of α-sulfopropionic acid being more satisfactory.

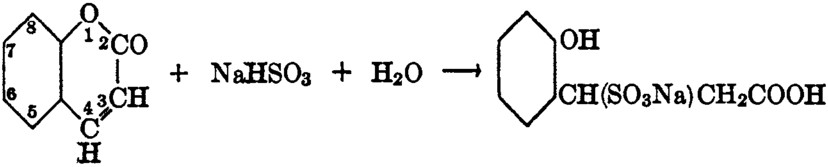
The unsaturated fatty acids add sodium bisulfite readily to give the corresponding sulfonates. When the double bond is in the α-position, β-sulfonic acids always result. Thus β-sulfobutyric acid is formed in good yields [343] from crotonic acid. Similarly cinnamic and tropic acids add a bisulfite to give the two β-sulfophenylpropionic acids.[344] A number of halogen substituted unsaturated acids add a bisulfite and then lose hydrogen halide. Thus α-bromoacrylic acid [345] behaves as follows.

$$CH_2{=}CHBrCOONH_4 + NH_4HSO_3 \rightarrow CH(SO_3NH_4){=}CHCOOH + NH_4Br$$

The resulting *cis*-β-sulfoacrylic acid is also formed from *trans*-β-chloroacrylic acid and concentrated ammonium sulfite at 70°. The *cis*-β-chloro acid similarly yields the *trans*-β-sulfo acid. This latter with strong potassium bisulfite is converted into β,β-disulfopropionic acid. By the action of ammonium sulfite upon the α-bromo- or β-chlorocrotonic acids there always results the same β-sulfocrotonic acid[346] and a disulfobutyric acid, probably the β,β-compound. The β-sulfocrotonic acid structure is evident from its reduction to β-sulfobutyric acid. Halogenation converts it into an α-halo-β-sulfocrotonic acid.

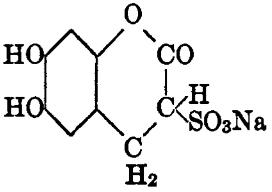
Benzoylacrylic acid reacts instantly with cold sodium bisulfite,[347] the keto group exerting an activating influence.

Mention of the reaction of sodium bisulfite with coumarin and its derivatives may be made here.[347,348] Dey and Row[349] believe that this reaction proceeds as follows.

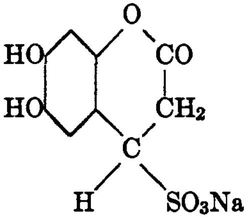


Good evidence for the presence of a phenolic group is available but the position of the sulfo group is assumed. If an alkyl or aryl group is attached to either of the unsaturated carbons no addition occurs; an acetyl or carbethoxy group does not have this inhibiting effect. 3,6-Dinitrocoumarin with sodium sulfite yields 5-nitrosalicylaldehyde.

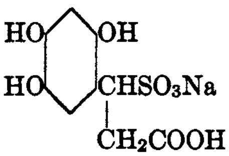
6,7-Dihydroxycoumarin (aesculitin) adds sodium bisulfite to form a sulfonate[350] which was believed to have structure I or II. It seems likely that an opening of the lactone ring may have occurred here as with coumarin to give III.



I



II

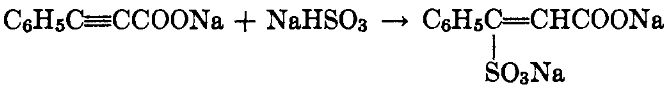


III

Treating the sodium salt with acetic anhydride eliminates sodium bisulfite giving the diacetate of the original product.[351] Heating the free acid to 95° also results in loss of the sulfo group with evolution of sulfur dioxide and water.

Sodium bisulfite does not add to umbelliferone, daphnetine, diethylaesculitin, and triethylaesculetinic acid.[350b]

Acetylenic acids and esters [352] add bisulfites. Propiolic acid reacts with ammonium sulfite to give *trans*-β-sulfoacrylic acid.[345] Methyl phenylpropiolate and methyl *n*-amylpropiolate give both mono- and disulfonates with sodium bisulfite [352] whereas sodium phenylpropiolate adds only one mole of the reagent.



$$C_6H_5C{\equiv}CCOONa + NaHSO_3 \rightarrow C_6H_5\underset{\displaystyle SO_3Na}{\underset{|}{C}}{=}CHCOONa$$

Other bisulfite addition reactions are given under the preparation of sulfodicarboxylic acids.

The conversion of unsaturated fatty acids or their glycerides into sulfonic acids has been mentioned frequently in the patent literature.[353] Such sulfonations may be effected in acetic acid or anhydride,[353a,b,c] sulfur dioxide,[353d] carbon tetrachloride,[353c] or a highly chlorinated ethylene.[353n,o] In addition, the sulfonations have been carried out in the presence of such diverse reagents as salts of acetic or sulfoacetic acid,[353f] a variety of phosphorus compounds,[353g,h] and chlorides of sulfur, boron, and other elements.[353i] Having an alkyl hydrogen sulfate present also has been suggested.[353j,h] If the sulfonation occurs in the presence of an aromatic hydrocarbon [353k,l] or phenol [353m] condensations likewise take place. Sulfonation of an oleic anilide may give a sulfonic acid [353p] of the aliphatic type.

Recently [353o] the action of sulfuric acid on camphenecarboxylic acids has been investigated. Sulfonic acids and sultones are formed.

The addition of chlorosulfonic acid to unsaturated acids may be considered to be a general method for preparing chlorosulfonic acids although it has received little attention outside of the technical literature. Thus, reaction occurs with undecylenic [354a] and oleic [354b] acids to give chloro compounds that lose hydrogen chloride very readily. This method may also be applied to unsaturated hydroxy acids [355] if enough chlorosulfonic acid is used to react with both the alcohol group and the double bond.

This method has been generalized in another manner by the claim [356] that sulfonic acids are formed by the action of the "onium" compound of a sulfonating agent stronger than sulfuric acid with an unsaturated acid. That true sulfonic acids are formed by the action of various sulfonating agents upon castor oil and other unsaturated oils seems to be no longer in doubt[357] but the precise nature of these acids is not yet known.

Sulfoacetic Acid and Derivatives. Sulfoacetic acid has been obtained in several ways other than those given in the general discussion of preparation methods. It is formed in good yields by the oxidation of thioglycolic acid with dilute nitric acid,[358] the corresponding disulfide with hydrogen peroxide,[151b] and of isethionic acid with chromic acid.[359] Oxidation of the disulfide of thioglycolic acid with silver sulfate gives a mixture containing some sulfoacetic acid.[360] The ureide of sulfoacetic acid is hydrolyzed to barium sulfoacetate by barium hydroxide.[361] Chlorosulfoacetic acid is reduced to the halogen-free compound by sodium amalgam.[304b] The most practical method of preparation is probably by the chloroacetic acid-sodium sulfite reaction already discussed (see p. 142).

Sulfoacetic acid is a hygroscopic solid which crystallizes as a monohydrate[271b] of m.p. 84–86°. Unlike malonic acid it is a very stable compound, undergoing no decomposition when boiled in dilute acid or alkali solution. By heating to 190° with concentrated sulfuric acid, carbon dioxide is evolved. With heat alone decomposition sets in[325a, b] at 245°. Bromination at 120° in water solution forms an unstable acid which loses carbon dioxide to give dibromomethanesulfonic acid.[361] Electrolytic oxidation[362] gives carbon dioxide and sulfuric acid.

Sulfoacetic acid in acetic anhydride is an efficient condensing agent[363] for the preparation of pyrylium salts and other complex products from methyl aryl ketones. Similarly a mixture of acetyl chloride with 0.025 times its weight of concentrated sulfuric acid is superior to other catalysts[364] for preparing benzopyrones and pyranones. Here also the active catalyst is probably sulfoacetic acid or a derivative of this.

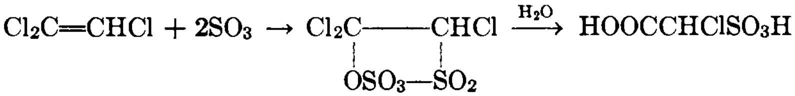
A thorough study has been made of various cobaltous and cupric salts[365] of sulfoacetic and sulfopropionic acids including a number of the coordination compounds containing pyridine. Because of the difference in acidity of the sulfo and carboxy groups the acid salts are sulfonates rather than acetates. The more common salts have been prepared by the investigators referred to under the preparation and reactions of the acid. By the reaction of phosphorus pentachloride upon the sodium salt, chlorination[366] as well as acid chloride formation occurs. From the dry silver salt and ethyl iodide there is obtained[325a, 367] the diethyl ester which was reported to undergo decomposition when distilled. Esterifying the free acid with alcohol yields the monoethyl ester,[322] $HO_3SCH_2COOC_2H_5$.

High-molecular-weight esters of sulfoacetic acid obtained by the action of a compound such as cetyl chloroacetate with sodium sulfite[368] are claimed to be of value as wetting, dispersing, emulsifying, or foam-producing agents. Similar claims are made for the amides made by the action of amines upon ethyl sodium sulfoacetate[369] or from the action of sodium sulfite upon N-alkylamides of chloroacetic acid.[370a] Amido esters of the general formula $\mathrm{RCONHCH_2CH_2OOCCH_2SO_3Na}$ have been described in patents.[370b] Compounds with the structure $\mathrm{RCOOCH_2CH_2NHCOCH_2SO_3Na}$ are also known.[370c]

$$\mathrm{C_{17}H_{35}NH_2 + NaO_3SCH_2COOC_2H_5 \rightarrow NaO_3SCH_2CONHC_{17}H_{35} + C_2H_5OH}$$

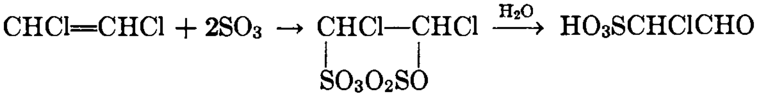
$$\mathrm{ClCH_2CONHR + Na_2SO_3 \rightarrow NaO_3SCH_2CONHR + NaCl}$$

The Halosulfoacetic Acids. Treating trichloroethylene with oleum followed by hydrolysis converts it into chlorosulfoacetic acid.[371]



$$\mathrm{Cl_2C{=}CHCl + 2SO_3 \rightarrow \begin{array}{c} Cl_2C\text{——}CHCl \\ |\qquad\quad | \\ OSO_3\text{—}SO_2 \end{array} \xrightarrow{H_2O} HOOCCHClSO_3H}$$

Interestingly enough, the acid can also be obtained from *sym*-dichloroethylene.[372]



$$\mathrm{CHCl{=}CHCl + 2SO_3 \rightarrow \begin{array}{c} CHCl\text{—}CHCl \\ |\qquad\quad | \\ SO_3O_2SO \end{array} \xrightarrow{H_2O} HO_3SCHClCHO}$$

$$\mathrm{2HO_3SCHClCHO + O_2 + 4NaOH \rightarrow 2NaO_3SCHClCOONa + 4H_2O}$$

By boiling trichloroacetic acid with potassium sulfite one of the chlorines is removed by reduction and another replaced by a sulfo group to give potassium chlorosulfoacetate.[373]

$$\mathrm{Cl_3CCOOK + 2K_2SO_3 + H_2O \rightarrow KO_3SCHClCOOK + 2KCl + KHSO_4}$$

The acid is also formed in small quantity by oxidation of pseudothiohydantoin[304b] with potassium chlorate and hydrochloric acid.

The free acid exists as very hygroscopic needles. It is reduced by sodium amalgam to sulfoacetic acid,[361b] a change which strangely enough also occurs by action of alcoholic ammonia at 140–160°. Bromination of the acid results both in bromine substitution and loss of carbon dioxide.

$$\mathrm{HO_3SCHClCOOH + Br_2 \rightarrow HO_3SCHClBr + CO_2}$$

The resolution of chlorosulfoacetic acid into its optically active components has been accomplished by the slow crystallization of its alkaloidal salts[374] from cold aqueous solution and in better yield by the use of *l*-hydroxyhydrindamine[375] in methanol. Neutral salts of the active forms of the acid are slowly racemized in aqueous solution even at room temperature. This is greatly accelerated by hydroxyl ions and, of course, by higher temperatures.

Bromosulfoacetic acid[376] has been prepared in 76% yield by bromination of sulfoacetic acid in hydrobromic acid solution at 80° in a sealed tube using a trace of iodine as a catalyst. The free acid melts at 119.5°.

The acid does not decompose in aqueous solution at 100°, but at 200° carbon dioxide is evolved. The pure acid undergoes a peculiar oxidation-reduction reaction when heated at 120°.

$$2HO_3SCHBrCOOH \rightarrow HO_3SCH_2COOH + [HO_3SCBr_2COOH]$$

$$[HO_3SCBr_2COOH] \rightarrow CHBr_2SO_3H + CO_2$$

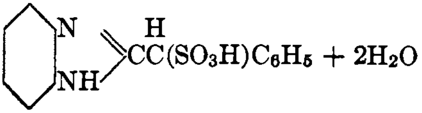
The dibromosulfoacetic acid is unstable and evolves carbon dioxide.

The resolution of bromosulfoacetic acid has been accomplished[377] by the cold crystallization of its alkaloidal salts as for the chlorine analog and also by the so-called method of hot crystallization using only the brucine salt. The racemization of the pure acid or its neutral salts is slow, but in alkaline solution proceeds very rapidly, quantitatively more readily than for the chloro compound.[378]

Phenylsulfoacetic Acid. The preparation of phenylsulfoacetic acid has already been mentioned (see p. 143). Heating an aqueous solution of a neutral salt of this acid causes racemization[379] as with a halogenated sulfoacetic acid. Heating the free acid with aniline gives the anilide, whereas with *o*-phenylene diamine an amidine results.

$$C_6H_5CH(SO_3H)COOH + 2C_6H_5NH_2 \rightarrow$$
$$C_6H_5CH(SO_3H_3NC_6H_5)CONHC_6H_5 + H_2O$$

$$C_6H_5CH(SO_3H)COOH + C_6H_4(NH_2)_2 \rightarrow$$



α-Sulfopropionic Acid and Derivatives. The monohydrate of *α-dl*-sulfopropionic acid melts at 100.5°. The acid salts are weak acids[380] apparently no stronger than propionic acid. It is probable that a neutral functional derivative such as the sulfonamide group would enhance the acid properties of the carboxyl group, but this is not true for the sulfonate ion. Resolution of the acid has been effected by the use of strychnine.[381] Reaction of the *dl*-acid with aromatic amines gives the arylammonium sulfonate of the carboxamide.[382]

The preparation of the α-chloro- and α-bromosulfopropionic acids has already been mentioned.[342] Both compounds have been resolved by means of their strychnine salts. The active forms are not racemized as are the corresponding acetic acid derivatives. This is no doubt because of the absence of hydrogen in the alpha position to the carboxyl group.

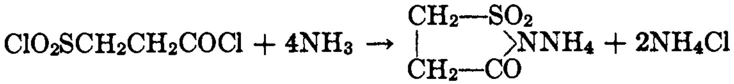
α-Sulfo-β-phenylpropionic acid[383] results from the reaction of a concentrated potassium pyrosulfite solution at 0° upon benzylbromoacetic acid. The active forms are racemized by heating in alkaline solution at 100° for several hours.

β-Sulfopropionic Acid and Derivatives; Cysteic Acid. β-Sulfopropionic acid has been prepared by the action of ammonium sulfite upon β-iodopropionic acid[315f,384] and through the catalytic reduction of the *cis* and *trans* β-sulfoacrylic acids.[385] It is one of the products formed in the action of a cupric,[386] silver,[360] or mercuric salt[387] upon *bis*-(β-carboxyethyl) disulfide. The reactions that occur are shown by the equations.

$$4(HOOCCH_2CH_2S)_2 + 9H_2O + 10CuSO_4 \rightarrow 5CuOOCCH_2CH_2SCu + 3HOOCCH_2CH_2SO_3H + 10H_2SO_4$$

$$3(NaOOCCH_2CH_2S)_2 + 5Ag_2SO_4 + 3H_2O \rightarrow 5AgOOCCH_2CH_2SAg + 5NaHSO_4 + HOOCCH_2CH_2SO_3Na$$

Several derivatives of the acid have been prepared by Bigelow and co-workers.[384] The action of ammonia produces a cyclic imide.



$$ClO_2SCH_2CH_2COCl + 4NH_3 \rightarrow \begin{matrix} CH_2\text{—}SO_2 \\ | \qquad\quad \\ CH_2\text{—}CO \end{matrix}\!\!>\!NNH_4 + 2NH_4Cl$$

Neutral alkyl esters were obtained from the silver salt.

$$AgO_3SCH_2CH_2COOAg + 2C_2H_5I \rightarrow C_2H_5O_3SCH_2CH_2COOC_2H_5 + 2AgI$$

It has been mentioned earlier that the conversion of cystine or cysteine to taurine (see p. 119) can be effected by oxidation and decarboxylation.[154,155a,b] The intermediate cysteic acid (α-amino-β-sulfopropionic acid) may be obtained in a variety of ways. Oxidation of cystine by oxygen occurs in the presence of hydrochloric but not sulfuric acid.[388] Copper salts accelerate the reaction.[389] Hydrogen peroxide is a satisfactory reagent, particularly in the presence of vanadic, tungstic, or molybdic acid,[390] or ferrous sulfate.[391] The reaction with iodine is practically quantitative[392] in acid solution.

$$(SCH_2CHNH_2COOH)_2 + 5I_2 + 6H_2O \rightarrow 2HO_3SCH_2CHNH_2COOH + 10HI$$

Peroxysulfuric acid also gives good results.[393] A study of the kinetics of the oxidation with thallic sulfate found the conversion to be second order with an activation energy of 24,200 cal.[394] The treatment of cystine with silver or copper salts results in a complex reaction where part of the cystine is reduced to cysteine and the remainder oxidized to cysteic acid[394, 395] or the sulfinic acid. It was shown by Simonsen[396] that in the iodine reaction a sulfinic acid is probably an intermediate step. If the oxidation is carried out in methyl cyanide with benzoyl hydrogen peroxide[397] the disulfone is formed. A small yield of cysteic acid results from the oxidation of human hair with 2% permanganate.[398] *l*-Cysteic acid crystallizes as needles while the *dl* form occurs as square or rectangular plates.[309] It would be expected that the free acid would have the dipolar ion formula, $\bar{O}_3SCH_2CHNH_3COOH$. A study of the titration curve[400] indicated that $Ka = 2 \times 10^{-9}$.

The decarboxylation of cysteic acid has already been mentioned.[155a, b, f] The rate of deamination[401] and the equilibrium with carbon dioxide[402] have been investigated. The rate of the absorption of cysteic acid from the intestine of the dog is intermediate between the rates for *dl*-methionine and *l*-cystine,[403] but it is oxidized and the sulfur is excreted more slowly than for cysteine and its other oxidation products or methionine[404] when fed in a human diet. The oxidation of cysteic acid that occurs in the rabbit is due to the microflora in the intestine.[405]

Glycylcysteic acid has been prepared in 91% yield by the oxidation of glycylcystine with bromine water.[406]

Higher Sulfonated Fatty Acids. The preparation of the sulfobutyric and higher fatty acids has already been mentioned (see p. 142). Resolution of α-sulfobutyric[320a, c] and valeric[407] acids has been effected through their alkaloidal salts. Heating a sulfo acid with an aromatic amine leads to anilide formation.

$$C_3H_7CH(SO_3H)COOH + 2C_6H_5NH_2 \rightarrow C_3H_7CH(SO_3NH_3C_6H_5)CONHC_6H_5 + H_2O$$

α-Sulfoisobutyric acid, obtained by the sulfonation method and also by oxidation of dimethylpseudothiohydantoin[330a] with potassium chlorate and hydrochloric acid, has been studied in some detail. It gives a dihydrate melting at 68°. Methyl α-sulfoisobutyrate results from heating the free acid with methanol containing hydrogen chloride. The dimethyl ester has been obtained from the silver salt and methyl iodide. This with methanol at 100° reverts to the mono ester.

$$(CH_3)_2C(SO_3H)COOH + CH_3OH \rightarrow (CH_3)_2C(SO_3H)COOCH_3 + H_2O$$

$$(CH_3)_2C(SO_3Ag)COOAg + 2CH_3I \rightarrow (CH_3)_2C(SO_3CH_3)COOCH_3 + 2AgI$$

$$(CH_3)_2C(SO_3CH_3)COOCH_3 + CH_3OH \rightarrow (CH_3)_2C(SO_3H)COOCH_3 + (CH_3)_2O$$

With ammonia the dimethyl ester reacts as follows.

$$(CH_3)_2C(SO_3CH_3)COOCH_3 + 2NH_3 \rightarrow (CH_3)_2C(SO_3NH_4)COOCH_3 + CH_3NH_2$$

Possibly under more vigorous reaction conditions, the second ester group would be converted to the amide. The neutral sodium salt of the acid with phosphorus pentachloride gives the acid chloride[276b] which reacts with methanol as follows.

$$(CH_3)_2C(SO_2Cl)COCl + CH_3OH \rightarrow (CH_3)_2C(SO_2Cl)COOCH_3 + HCl$$

$$(CH_3)_2C(SO_2Cl)COOCH_3 + 3NH_3 \rightarrow (CH_3)_2C(SO_2NH_2)CONH_2 + NH_4Cl + CH_3OH$$

Ammonia reacts with the product as indicated to give the diamide. This decomposes at about 340° without melting. Attempts to prepare by action with urea an analog of barbituric acid were unsuccessful. This series of reactions demonstrates in an excellent manner the different behavior of the sulfonic and carboxylic acids toward various reagents.

The β-sulfocarboxylic acids are usually made from the addition of a bisulfite to an unsaturated acid as indicated earlier. β-Sulfobutyric acid has also been obtained by oxidation of the thiol with bromine in aqueous solution.[408] The most notable difference between the α- and β-sulfo acids is in the resistance to racemization shown by the active forms of the latter.

Disulfocarboxylic Acids. A few disulfocarboxylic acids are known. Aside from the addition of bisulfites to acetylenic acids already mentioned,[852] they have been obtained from the bisulfite addition products of unsaturated aldehydes and malonic acid. In the case of acrolein[409] this occurs as shown below.

$$CH_2{=}CHCHO + 2KHSO_3 \rightarrow KO_3SCH_2CH_2CHOHSO_3K$$

$$KO_3SCH_2CHOHSO_3K + CH_2(COOH)_2 \rightarrow KO_3SCH_2CH_2CH(SO_3K)CH_2COOH + CO_2 + H_2O$$

In addition to the crystalline potassium salt whose formula is given in the equation, an isomer was also present, but this was not isolated in a pure state. The free acids were obtained only as syrups. Aniline reacts with β,δ-disulfovaleric acid readily.

$$HO_3SCH_2CH_2CH(SO_3H)CH_2COOH + 3C_6H_5NH_2 \rightarrow C_6H_5NH_3O_3S(CH_2)_2CH(SO_3NH_3C_6H_5)CH_2CONHC_6H_5 + H_2O$$

Both acids with potassium hydroxide decompose into vinylacrylic acid.

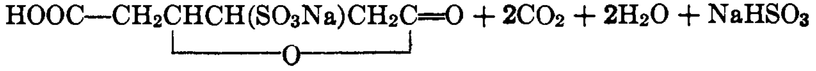
A disulfonic acid has also been obtained from crotonic aldehyde, aniline again reacting to give a crystalline derivative.

$$CH_3CH(SO_3K)CH_2CHOHSO_3K + CH_2(COOH)_2 \rightarrow CH_3CH(SO_3K)CH_2CH(SO_3K)CH_2COOH + CO_2 + H_2O$$

Fusion of the acid with alkali decomposed it to sorbic acid in 50% yields.

Cinnamic aldehyde behaves exactly the same as the simple aliphatic aldehydes except for the formation of a small amount of by-product, an unsaturated sulfonic acid of the formula $C_6H_5CH(SO_3H)CH_2CH{=}CHCOOH$. The success of this type of condensation reaction depends partly upon the stability of the bisulfite addition compound. Potassium hydrogen malonate may be used instead of malonic acid, but attempts to carry out the reaction with methylmalonic acid, succinic acid, or arylacetic acids were unsuccessful. Condensation of glyoxal sodium bisulfite with malonic acid[410] produces β-hydroxy-β′-sulfoadipic acid lactone.

$$(CHOHSO_3Na)_2 + 2CH_2(COOH)_2 \rightarrow$$



$$HOOC{-}CH_2\underbrace{CHCH(SO_3Na)CH_2C}_{O}{=}O + 2CO_2 + 2H_2O + NaHSO_3$$

SULFODICARBOXYLIC ACIDS

Although sulfomalonic acid is too unstable to be obtained in the free state, a number of compounds supposedly related to this are known. Cyanoacetanilide[411] and other similarly substituted amides are readily sulfonated by chlorosulfonic acid in chloroform solution, a reaction which was interpreted by its investigators to proceed as follows.

$$NCCH_2CONHC_6H_5 + 2ClSO_3H \rightarrow NCC(SO_3H)_2CONHC_6H_5 + 2HCl$$

In view of the ease with which anilides are sulfonated and the fact that cyanoacetamide did not sulfonate under the same conditions, at least one of the sulfo groups is probably in the aromatic nucleus. The sulfonation of malonanilide[412] can be explained in a similar manner. However, the monosulfonic acid obtained from N,N′-di-*n*-propylmalonamide is undoubtedly a true sulfodicarboxylic acid derivative. The claim that arylamides of methylmalonic acid disulfonate as shown in the equation seems very improbable, at least one of the sulfo groups more likely entering an aromatic nucleus. Higher alkylamides[413] of

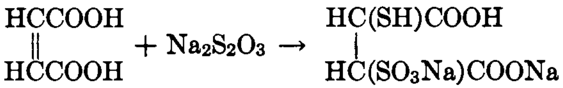
$$CH_3CH(CONHAr)_2 + 2ClSO_3H \rightarrow HO_3SCH_2C(SO_3H)(CONHAr)_2 + 2HCl$$

sulfomalonic acid salts have been patented as wetting agents.

Sulfosuccinic acid has been obtained in a variety of ways. It results from the action of sulfur trioxide[414] upon succinic acid, from succinyl chloride and silver sulfate,[327] by oxidation of thiolsuccinic acid with nitric acid,[415] and by oxidation of pseudothiohydantoinacetic acid with chloric acid.[416] Sodium sulfite reacts with bromosuccinic acid[417] to give a mixture of fumaric, maleic, and sulfosuccinic acids. α,α'-Dibromosuccinic acid[316] with potassium bisulfite is first converted into fumaric acid which then adds a second mole of bisulfite to give the sulfo compound.[347, 418] Maleic acid[418, 419] likewise adds a bisulfite, the reaction occurring more rapidly than with fumaric acid. The acid salts of fumaric acid react more rapidly than the neutral ones while for maleic acid the reverse is true. In these reactions and other similar ones a systematic study of the influence of the *p*H of the mixture upon reaction rate would give interesting results.

Sulfosuccinic acid is a very soluble hygroscopic compound which, however, has been obtained in crystalline form.[418] By heating with strong potassium hydroxide it is decomposed[419] into the potassium salts of sulfurous, oxalic, acetic, and sulfoacetic acids. The racemization of the active forms of sulfosuccinic acid occurs readily. Higher alkyl esters and amides of sulfosuccinic acid are excellent wetting agents.[420]

Addition of sodium thiosulfate to maleic acid[421] gives a small amount of thiolsulfosuccinic acid.



$$\begin{array}{l}HCCOOH\\ \|\\ HCCOOH\end{array} + Na_2S_2O_3 \rightarrow \begin{array}{l}HC(SH)COOH\\ |\\ HC(SO_3Na)COONa\end{array}$$

The sym-*dl*-disulfosuccinic acid results by addition of a bisulfite to acetylenedicarboxylic acid,[422] reaction of a bisulfite with bromomaleic or bromofumaric acid, and sulfonation of succinic anhydride with sulfur trioxide. None of the *meso* acid was isolated from the products of any of these reactions. The pure acid melts at 160°. It may be resolved as the strychnine salt.

The preparation of the various sulfomethylsuccinic acids [347,423] may be summarized by the following equations.

$$CH_2{=}C(COOH)CH_2COOH + KHSO_3 \rightarrow$$
$$KO_3SCH_2CH(COOH)CH_2COOH \quad (85\%\ \text{yield})$$

$$CH_2BrCH(COOH)CH_2COOH + K_2SO_3 \rightarrow$$
$$KO_3SCH_2CH(COOH)CH_2COOH + KBr \quad (\text{Side reactions reduce the yield obtained by this method.})$$

$$CH_3CH(COOH)CH(COOH)_2 + SO_3(\text{or } ClSO_3H) \rightarrow$$
$$CH_3CH(COOH)CH(SO_3H)COOH + CO_2(+\ HCl)$$

A 40% yield of the barium salt was obtained by the chlorosulfonic acid method in this last reaction. This acid could not be prepared from the proper bromo compound and aqueous sodium sulfite, hydrolysis occurring. It has been obtained by oxidation of thiohydantoin-α-propionic acid.[424]

The addition of a bisulfite to citraconic acid gives the best yield of this isomeric acid.[423,424,425]

$$CH_3CBr(COOH)CH_2COOH + K_2SO_3 \rightarrow$$
$$CH_3C(SO_3K)COOHCH_2COOH$$

$$CH_3C(COOH){=}CHCOOH + KHSO_3 \rightarrow$$
$$CH_3C(SO_3K)(COOH)CH_2COOH \quad (84\%\ \text{yield})$$

$$CH_3CH(COOH)CH_2COOH + SO_3 \rightarrow$$
$$CH_3C(SO_3H)(COOH)CH_2COOH$$

All three sulfomethylsuccinic acids have been resolved into their active forms. As would be predicted, the acid in which there is no hydrogen attached to the asymmetric carbon atom is highly resistant to racemization. A considerable number of salts of these acids have been prepared.

Oxidation of sulfocamphyllic acid[426] with nitric acid gives a sulfoisopropylsuccinic acid, $HOOCCH_2CH[C(SO_3H)(CH_3)_2]COOH$.

By the direct sulfonation of glutaric acid or from the reaction of alkali sulfite upon the dibromoglutaric acid there are obtained both the *meso* and *dl-α,α'*-disulfoglutaric acids.[427] Glutaconic acid adds sodium bisulfite[428] to give the β-sulfoglutaric acid.

Two unsaturated sulfodicarboxylic acids are known. Sulfonation of maleic or fumaric acid with excess sulfur trioxide[429] occurs readily at 60–70° apparently without attacking the double bond. The addition of potassium bisulfite to acetylenedicarboxylic acid gives only a trace of the primary addition product because the second molecule adds more rapidly than the first.

β-Chloroglutaconic acid with potassium bisulfite[430] gives β-sulfoglutaconic acid, the primary addition product losing hydrogen chloride. The second molecule of bisulfite adds slowly so it is possible to prepare the β-sulfoglutaconic acid[431] from glutinic acid ($HOOC—C{\equiv}C—CH_2$-$COOH$).

ALKANEDISULFONIC ACIDS

Methanedisulfonic (Methionic) Acid. Methionic acid has been extensively investigated, partly because it is readily obtainable and partly owing to its formal relationship to malonic acid.

It is produced in small amounts in a number of reactions involving the use of sulfur trioxide or fuming sulfuric acid. Thus, it has been isolated from the reaction mixture obtained by sulfonating ethyl ether,[432] ethyl sulfate,[433] acetonitrile, acetamide, sulfoacetic acid,[434] acetic acid,[435] and lactic acid.[436] Acetylene dissolves readily in 50% fuming sulfuric acid[437] to give mostly formylmethionic acid, but a small amount of this decomposes to form methionic acid. Similar results are attained by sulfonation of acetaldehyde.[438]

$$OHCCH(SO_3H)_2 \rightarrow CO + CH_2(SO_3H)_2$$

In addition, it has been prepared by the action of potassium sulfite upon chloroform, iodoform,[86b] and potassium trichloromethanesulfonate,[439] and in small yields from the reaction of ammonium sulfite with 1,1,2-trichloroethane[440] or the corresponding bromine compound. Reduction of diiodomethionic acid with sodium amalgam converts it into methionic acid.[441] Potassium sulfite[434a] also does this. Oxidation of methylene trithiocarbonate[442] and of methylene thiocyanate[83] have also been mentioned as sources of the acid.

One of the most satisfactory methods of preparation involves the decomposition of formylmethionic acid by aqueous alkali.[437] This is readily obtainable by the action of fuming sulfuric acid upon acetylene[439] or acetaldehyde,[438] and from potassium sulfite and chloral hydrate.[443]

The reaction of methylene chloride[444] with potassium sulfite also has been recommended as a convenient method of preparation, the potassium methionate being produced in 85% yield.

Pure methionic acid is a hygroscopic crystalline material[437c] which is strongly acidic in aqueous solution.[445] It forms a solid hydrate which separates from a concentrated water solution. The barium salt of the acid is sufficiently insoluble in alcohol to make it useful in the quantitative determination of the acid.[437c] A large number of other salts have been investigated[446] in some detail.

The acid is very stable toward heat, acid, and alkali.[447] In heating the acid above 160° slight decomposition occurs, but it may be distilled practically unchanged in a high vacuum.[437c] Heated with 20% of its weight of water at 220–270° under 15–20 mm. pressure, it decomposes with formation of methanesulfonic acid and sulfuric acid.

It is claimed[448] that methionic acid may be condensed with "hexadecene" in the presence of dehydrating agents to give a high-molecular-weight sulfonic acid of value in the textile industry. Substantially the same claims are made for the product obtained from methionic acid and butyl ricinoleate.[449]

No reaction occurs when methionic acid is heated with strong oxidizing agents such as nitric acid or chlorine.[434a] Methionic acid cannot be esterified by heating with an alcohol. Under these conditions ethers[450a, b] are formed at temperatures similar to those required when sulfuric acid is the reagent employed. The methyl and ethyl esters have been obtained, however, by the action of the alkyl iodides upon silver methionate.[437c, 451] The methyl ester is a solid (m.p. not given) which distils at 194–200°/16 mm. and the ethyl homolog melts at 28–29°. The lower alkyl esters have also been obtained in an impure state by the action of methanedisulfonyl chloride on the alcohols. If the temperature is allowed to rise appreciably the ester is decomposed to the acid.

$$CH_2(SO_2Cl)_2 + 2ROH \rightarrow CH_2(SO_2OR)_2 + 2HCl$$

$$CH_2(SO_2OR)_2 + 2ROH \rightarrow 2R_2O + CH_2(SO_3H)_2$$

Undoubtedly the use of a base such as pyridine and good temperature control would make this a satisfactory method of preparation.

Unlike the alkyl esters, the aryl esters, which can be obtained from phenols and the acid chloride, are very stable compounds.[450b] They dissolve readily in dilute alkali but are precipitated unchanged by acids. Hydrolysis occurs only by heating with 50% sodium hydroxide, while the alkyl esters are completely hydrolyzed by hot water in which the methyl ester is readily soluble. While the aryl esters are acidic enough to form alkali metal salts in aqueous solution, the alkyl esters give these only in an anhydrous solvent such as benzene through the action of the metal, and the salts are decomposed by either alcohol or water. Thus phenyl methionate is apparently a stronger acid than ethyl malonate whereas the alkyl methionates are weaker. The alkali metal derivatives of both alkyl and aryl esters are readily alkylated by alkyl iodides or methyl sulfate. This provides a method for the synthesis of homologs of methionic acid that would be otherwise difficult to obtain. It seems of some interest that the alkyl sodiomethionates do not appear to undergo intramolecular alkylation which might be expected to take place as follows.

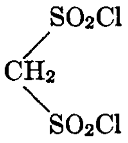
$$NaCH(SO_3CH_3)_2 \rightarrow CH_3CH(SO_3Na)SO_3CH_3$$

An attempt[450b] to prepare benzyl methionate from benzyl chloride and silver methionate in benzene solution gave diphenylmethane. Silver sulfate was then also found to act as a catalyst in this reaction.

$$C_6H_5CH_2Cl + C_6H_6 \xrightarrow{CH_2(SO_3Ag)_2} C_6H_5CH_2C_6H_5 + HCl$$

A mixed ester, methyl phenyl methionate, has been prepared by the action of methyl iodide upon silver phenyl methionate.[452] In water the methyl group is rapidly hydrolyzed.

Methanedisulfonyl chloride may be prepared by the action of phosphorus pentachloride upon the dry acid.[450b, 451, 453] This exists in two forms which melt at 8° and 37°. The liquid distils at 133°/10 mm. and has the d_4^{22} of 1.821. The report of Kohler[454] that phosphorus pentachloride with potassium methionate gives chloromethanedisulfonyl chloride was not verified[450b] although the reaction was admittedly not the normal one. It is possible that the two forms of the chloride correspond to formulas I and II, but this is unlikely as II requires the presence of a four-atom ring and, what is more important, calls for an enlarged valence shell for sulfur. The two forms are probably only different crystalline modifications.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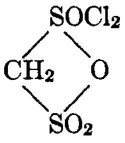

II

Some of the reactions of the acid chloride are anomalous. It does not give the amide with ammonia or diethylamine, producing instead a complex mixture of which the components were not satisfactorily identified.[450b] With aniline, however, the disulfonanilide results normally.[453] In benzene solution aluminum chloride effects the formation of chlorobenzene and a resin. The latter may arise from methylene sulfone, an analog of ketene.

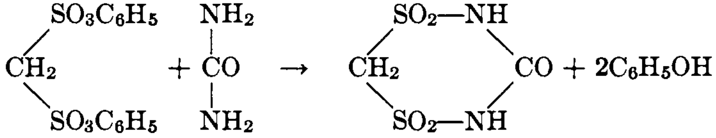
$$CH_2(SO_2Cl)_2 + C_6H_6 \xrightarrow{AlCl_3} [CH_2{=}SO_2] + C_6H_5Cl + SO_2 + HCl$$

The acid chloride reacts rapidly with water at a low temperature to form methionic acid quantitatively, in contrast with the behavior of the 1,2-disulfonyl chlorides.[455]

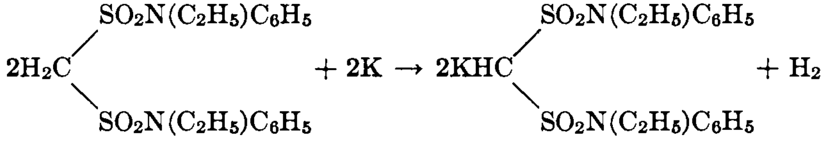
Methanedisulfonamide has been obtained by the action of excess ammonia on phenyl methionate. Both this and the monoamide are acidic compounds. The barium salt of the latter is similar to barium methionate in its insolubility in water but differs in being readily soluble in dilute hydrochloric acid.[450b, 456] Heating phenyl methionate with excess *tert*-butylamine to 160° yields the disulfonamide. With one mole of aniline the reaction is that shown below.

$$CH_2(SO_3C_6H_5)_2 + C_6H_5NH_2 \rightarrow CH_2(SO_2NHC_6H_5)SO_3C_6H_5 + C_6H_5OH$$

With urea, phenyl methionate forms a cyclic ureid, an analog of barbituric acid.[450b, c] It would be of interest to study the physiological action of derivatives of this compound.



The dianilide of methionic acid is strongly acidic while the amide obtained from N-ethylaniline is insoluble in water and alkali. This is in contrast with phenyl methionate which is readily soluble in alkali. The amide, however, does react more readily with sodium or potassium in benzene solution with evolution of hydrogen than do the alkyl methionates.[450b]



The resulting alkali metal compound may be alkylated by an alkyl iodide or methyl sulfate. The hydrolysis of the resulting amide by hydrochloric acid is a satisfactory reaction for preparing homologs of methionic acid.

The reaction of hydrazine hydrate with phenyl methionate is quite complex.[452] Steam distillation removes phenol and phenyl methanesulfonate from the reaction mixture, methiondihydrazide and phenyl methionhydrazide remaining behind. At a higher reaction temperature (155°) a mixture of ammonium salts and amides resulted, but no hydrazide was isolated. Phenyl methylmethionate behaves in a similar manner.

Halomethionic Acids. A number of the halogen derivatives of methionic acid have been investigated. Chloromethionic acid results in 5–10% yields as a by-product from the action of sulfur trioxide upon chloroacetic acid in the preparation of chlorosulfoacetic acid.[340, 374b, 457]

$$CH_2ClCOOH + 2SO_3 \rightarrow HCCl(SO_3H)_2 + CO_2$$

Probably the best method of preparation is the decomposition of formylchloromethionic acid which occurs in alkaline solution at room temperature.[458]

$$HCOCH(SO_3K)_2 + Cl_2 \rightarrow HCOCCl(SO_3K)_2 + HCl$$

$$HCOCCl(SO_3K)_2 + NaOH \rightarrow HCCl(SO_3K)_2 + HCOONa$$

The free acid forms an extremely soluble dihydrate which melts at 96–97°. The crystallographic properties of a number of salts of the acid have been investigated.[457] The potassium salt is precipitated from its concentrated aqueous solution by the addition of alcohol. Chlorine reacts with the sodium salt of N,N′-diethyl-N,N′-diphenylmethionamide[450b] to give the chloro derivative. By repeating the sodium and chlorine treatment the dichloro compound results, a reaction not possible with bromine or iodine. Heating the monochloro amide with potassium acetate and acetic acid at 200° for 4 hours eliminates one of the sulfo groups forming chloromethanesulfonethylanilide, $ClCH_2SO_2N(C_2H_5)C_6H_5$, as well as some ethylacetanilide, $CH_3CON(C_2H_5)C_6H_5$.

Bromomethionic acid is a by-product in the sulfonation of bromoacetic acid.[341] It is obtained in 86% yields by alkaline hydrolysis of formylbromomethionic acid,[459] in 25% yield by bromination of methionic acid, in 70% yield through decomposition of diazomethionic acid with hydrobromic acid, and in small amount from the reaction of potassium sulfite with potassium dibromomethanesulfonate. The N-ethylanilide has been obtained by bromination of the ethylanilide of methionic acid.[450b]

The strychnine salt of bromomethionic acid is insoluble enough to be of value in isolating and purifying the acid. The free acid crystallizes as a dihydrate, m.p. 125–126°. Iodo- and diïodomethionic acid have been obtained from diazomethionic acid, a reaction also mentioned later.[462]

Aminomethionic Acid and Derivatives. Aminomethionic acid is readily made by an interesting reaction involving potassium cyanide and potassium bisulfite.[460]

$$KCN + 2KHSO_3 + H_2O \rightarrow H_2NCH(SO_3K)_2 + KOH$$

Addition of hydrochloric acid to the reaction mixture precipitates the slightly soluble potassium hydrogen aminomethionate, a compound which is acidic to phenolphthalein and titrates as a monobasic acid. The normal potassium or barium salt decomposes in boiling water solution. The free acid is known only in dilute solution, and attempts to concentrate this lead to evolution of ammonia and sulfur dioxide even at room temperature. Acetylation of the potassium salt produces the amide[460c] which with perchloric acid gives the free acid.

$$H_2NCH(SO_3K)_2 + (CH_3CO)_2O \rightarrow CH_3CONHCH(SO_3K)_2 + CH_3COOH$$

$$CH_3CONHCH(SO_3K)_2 + 2HClO_4 \rightarrow CH_3CONHCH(SO_3H)_2 + \underline{2KClO_4}$$

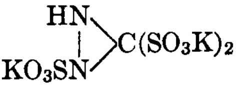
This and other acyl derivatives are obtainable in a pure state. Potassium cyanate reacts to form the urea derivative, which is not formed from the action of alcoholic ammonia on carbethoxyaminomethionic acid.

Nitrous acid reacts with aminomethionic acid to give the diazo compound in good yields.[460b,461] The varied reactions of this product are of considerable interest. It is stable in hot alkaline solution but decomposes in an acid or neutral solution in a manner which may be explained by the following equations.

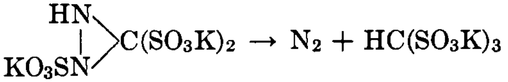
$$N_2C(SO_3K)_2 + H_2O \rightarrow N_2 + [HOCH(SO_3K)_2]$$

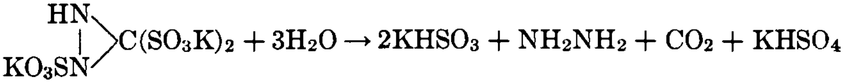
$$[CHOH(SO_3K)_2] + H_2O \rightarrow HCOOH + 2KHSO_3$$

$$N_2C(SO_3K)_2 + KHSO_3 \rightarrow$$



This last compound which was also obtained in separate experiments from potassium bisulfite and the diazo compound breaks down to potassium methanetrisulfonate.[462a] In acid solution hydrazine is also produced. The instability of the hydroxymethionic acid is to be expected although a derivative of the dihydroxy acid is known.[462b] With hydrogen iodide or iodine, nitrogen is eliminated as with other diazo compounds.





$$N_2C(SO_3K)_2 + HI \rightarrow IHC(SO_3K)_2 + N_2$$

$$N_2C(SO_3K)_2 + I_2 \rightarrow I_2C(SO_3K)_2 + N_2$$

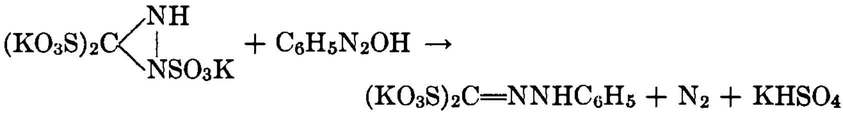
This is the only practical method for preparing the iodomethionic acids.

When heated to 120–130° the diazo compound liberates nitrogen to form a rather unstable azine derivative.

$$2N_2C(SO_3K)_2 \rightarrow N_2 + [\text{—}N{=}C(SO_3K)_2]_2$$

Heavy metal salts also cause the liberation of nitrogen and precipitation of the free metal. The nature of the other products formed in this last reaction was not determined.

The potassium bisulfite addition product of potassium diazomethionate undergoes a series of interesting reactions with benzenediazonium hydroxide.[461] For details the original should be consulted.



Thiolmethionic Acid. The compound obtained by the action of potassium sulfite upon trichloromethylsulfur chloride[458, 463] was until comparatively recently[464] believed to be thiolmethanetrisulfonic acid, a formula now discarded for that of thiosulfomethionic acid. The equation for its formation may then be written as follows.

$$Cl_3CSCl + 4K_2SO_3 + H_2O \rightarrow (KO_3S)_2CHSSO_3K + KHSO_4 + 4KCl$$

On oxidation with bromine methanetrisulfonic acid results.[375]

$$(KO_3S)_2CHSSO_3K + 3Br_2 + 4H_2O \rightarrow HC(SO_3K)_3 + 6HBr + KHSO_4$$

The absence of the thiol group is indicated because the tripotassium salt is neutral, no precipitate is formed with mercury, copper, or lead salts, and the behavior with alkali and ferric chloride is similar to that of thiosulfo derivatives of carboxylic acids. Upon heating the dry salts of the acid or solutions of the salts with hydrochloric acid, evolution of sulfur dioxide occurs. The potassium salt reacts with mercuric oxide in a manner suggesting the presence of the thiol group. This, however, occurs because of hydrolysis of the thiosulfuric acid radical, the net result being expressed by the equation.

$$(KO_3S)_2CHSSO_3K + HgO \rightarrow KO_3SCHS(SO_3)Hg + K_2SO_4$$

Silver nitrate behaves in an analogous manner.

$$KO_3S_2CH(SO_3K)_2 + H_2O + 2AgNO_3 \rightarrow AgSCH(SO_3Ag)SO_3K + 2KNO_3 + H_2SO_4$$

The mercury or silver compound can be converted to the monopotassium salt by hydrogen sulfide. Oxidation of this thiol with chlorine or bromine water gives methanetrisulfonic acid.

$$HSCH(SO_3K)_2 + 3Cl_2 + 3H_2O \rightarrow HC(SO_3H)_3 + 6HCl$$

Iodine, or cupric or ferric salts carry the oxidation to the disulfide[465] stage.

$$HSCH(SO_3H)_2 + 2CuCl_2 \rightarrow [SCH(SO_3H)_2]_2 + 2HCl + Cu_2Cl_2$$

Chlorine water converts the disulfide into methanetrisulfonic acid while hydrogen peroxide produces further decomposition to sulfuric acid. Nitric acid and potassium permanganate also give this as the final product of oxidation of the thiolmethionic acid. Reduction with zinc results in evolution of hydrogen sulfide. The other product, which was not isolated, is probably methionic acid.

Thiolmethionic acid titrates as a dibasic acid with methyl orange while with phenolphthalein three equivalents of alkali react. Heating with excess alkali decomposes the disulfide with probable formation of a sulfenic acid, since ferric chloride gives a blue coloration with the resulting solution.

$$[SCH(SO_3K)_2]_2 + 2KOH \rightarrow KSCH(SO_3K)_2 + [KOSCH(SO_3K)_2] + H_2O$$

Boiling an aqueous solution of the lead salt causes a decomposition which was postulated to occur as follows.

$$2[SCH(SO_3)_2Pb]_2 \rightarrow Pb[SCH(SO_3)_2Pb]_2 + [SCH(SO_3H)SO_3]_2Pb$$

The last compound was not isolated, however.

Acylmethionic Acids. Several acyl derivatives of methionic acid have been prepared. These are, of course, derivatives of aldehydes and ketones. The simplest of these, the formyl derivative (disulfoacetaldehyde) has already been mentioned as a source of methionic acid. The N-ethylanilide of this acid is produced,[450b] as shown in the equation, by a Claisen condensation.

$$NaCH[SO_2N(C_2H_5)C_6H_5]_2 + HCOOCH_3 \rightarrow HCOCH[SO_2N(C_2H_5)C_6H_5]_2 + NaOCH_3$$

This compound titrates as a monobasic acid so probably exists in the hydroxymethylene form, $HOCH{=}C[SO_2N(C_2H_5)C_6H_5]_2$. The sodium bisulfite addition product of sodium formylmethionate has been patented as a reducing agent which possesses certain desirable qualities.[466] Formylmethionic acid is reported to condense with cetyl formal in the presence of sulfuric acid to give wetting agents.[467] The chemistry of this condensation is not evident. Acetonetetrasulfonic acid also reacts in this manner. The condensation of formylmethionic acid with a variety of other compounds has been mentioned.[468]

The benzoyl derivatives of phenyl and the cresyl methionates[450b] have been obtained by the action of benzoyl chloride upon the sodium derivatives of the esters.

$$C_6H_5COCl + NaCH(SO_3C_6H_5)_2 \rightarrow C_6H_5COCH(SO_3C_6H_5)_2 + NaCl$$

Apparently the free keto acids or their salts have not been made.

Alkylmethionic Acids. Most of the homologs of methionic acid have been obtained by alkylation of an ester or amide of methionic acid followed by hydrolysis. Ethane-1,1-disulfonic acid is, however, an exception, as it has most frequently been prepared by oxidation of thialdine[469] with potassium or zinc permanganate. The reaction of ammonium sulfite with ethylidene chloride does not yield an appreciable quantity of the disulfonate.[469] Ethyl iodide with silver ethane-1,1-disulfonate gives the ethyl ester.[470] It has also been obtained by alkylation of the sodium derivative of ethyl methionate in benzene solution with methyl iodide.[450b] It was described as an oil of "peculiar" odor. It is insoluble in water and cold alkali but with sodium ethoxide in ether a precipitate of the sodium salt forms readily.

$$CH_3CH(SO_3C_2H_5)_2 + NaOC_2H_5 \rightarrow CH_3CNa(SO_3C_2H_5)_2 + C_2H_5OH$$

By warming this with ethyl iodide in alcohol solution both alkylation and loss of the ester groups occur, butane-2,2-disulfonic acid resulting. The ester also reacts rapidly with alcoholic ammonia[471] with formation of ethylamine and the ammonium sulfonate.

Phenyl ethane-1,1-disulfonate and the corresponding N-ethylanilide and phenetidide result from methylation of the sodiomethionate derivatives.[450b, c, 456] These are hydrolyzed in alcoholic alkali with cleavage of the carbon-sulfur bond.

$$CH_3CH[SO_2N(C_2H_5)C_6H_4OC_2H_5]_2 + 3NaOH \rightarrow CH_3CH(OH)SO_3Na + 2C_2H_5OC_6H_4NHC_2H_5 + Na_2SO_3$$

In toluene saturated with ammonia at 20° phenyl ethane-1,1-disulfonate yields the monosulfonamide while at 130° in a sealed tube both ester groups react.

Ethane-1,1-disulfonyl chloride, prepared from the free acid and phosphorus pentachloride, is a yellow oil, b.p. 125–126° (15 mm.). Potassium methionate when heated with the same reagent[454] gives chloromethanesulfonyl chloride rather than the acid chloride and the ethane homolog behaves similarly, except for the position taken by the chlorine.

$$CH_3CH(SO_3K)_2 + 3PCl_5 \rightarrow ClCH_2CH_2SO_2Cl + SO_2Cl_2 + 2KCl + 2POCl_3 + PCl_3$$

Some 1-chloroethane-1-sulfonyl chloride and 1,2-dichloroethane-1-sulfonyl chloride are also formed.

The formyl derivative of methylmethionic acid can be obtained by the action of 50% fuming sulfuric acid[472] upon propionaldehyde. By alkali treatment the aldehyde group is readily removed.

$$CH_3CH_2CHO + 2SO_3 \rightarrow CH_3C(SO_3H)_2CHO$$

$$CH_3C(SO_3H)_2CHO + 3NaOH \rightarrow CH_3CH(SO_3Na)_2 + HCOONa + 2H_2O$$

Sulfonation of acetone under similar conditions gives a trisulfonic acid. The structure was proved by its reaction with alkali.

$$HO_3SCH_2COCH(SO_3H)_2 + 4NaOH \rightarrow NaO_3SCH_2COONa + CH_2(SO_3Na)_2 + 3H_2O$$

In addition to methylmethionic acid and related compounds, Schroeter and co-workers[450b] have prepared the dimethyl, ethyl, allyl, 2,3-dibromopropyl, methylethyl, methylallyl, methyl-2,3-dibromopropyl, benzyl, benzylmethyl, and *p*-nitrobenzyl derivatives. Several others have been prepared more recently by Klaver.[456] *n*-Propyl- and *n*-butylmethionic acids were obtained by the alkylation of phenyl methionate with the alkyl *p*-toluenesulfonates followed by hydrolysis. The chemistry of these is essentially the same as that of the methylmethionic acid.[450c]

Ethane-1,2-disulfonic Acid and Related Compounds. Of the disulfonic acids with the two sulfo groups not attached to the same carbon those in which they are joined to adjacent carbons are of most interest.

Ethane-1,2-disulfonic acid has been obtained by the oxidation of ethane-1,2-dithiol,[473] ethylene thiocyanate,[454, 474] and several cyclic compounds [475] with sulfur linked to adjacent carbons. Small yields are formed in the sulfonation of ethyl cyanide or propionamide [476] and nitroethane [477] and by the electrolysis of barium sulfoacetate.[478] It is obtained in 95% yields by the action of a saturated alkali sulfite solution upon ethylene bromide [36c, 454, 479] at the boiling point of the mixture. Treating 1,1,2-tribromoethane with boiling ammonium sulfite [440] also gives some ammonium ethane-1,2-disulfonate.

The free acid, m.p. 104°, has been obtained from the lead salt by treatment with hydrogen sulfide [455] and by decomposing the ammonium salt with fuming nitric acid.[454] It readily crystallizes from a mixture of acetic acid and acetic anhydride.

A great many salts of the acid have been studied.[480] The sodium salt when fused with alkali [481] evolves acetylene and hydrogen. Sodium sulfite is the other product.

The disulfonyl chloride may be prepared by the action of phosphorus pentachloride on the sodium salt [482] or free acid.[454] It is also formed in quantitative yields from the action of carbonyl chloride [454] with the acid in toluene solution.

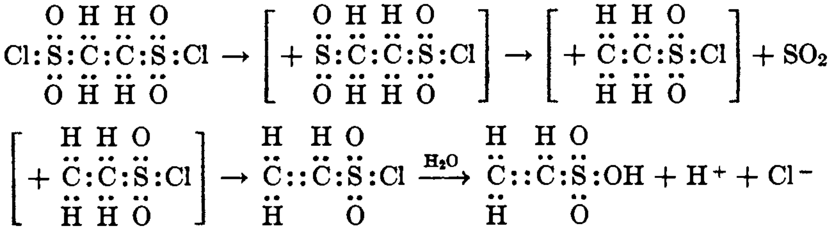
$$(CH_2SO_3H)_2 + 2COCl_2 \rightarrow (CH_2SO_2Cl)_2 + 2CO_2 + 2HCl$$

All attempts to prepare an isomeric sulfonyl chloride have been unsuccessful. This non-existence of an isomeric disulfonyl chloride is readily explainable upon the basis of the sulfur-oxygen bond being a "semi-polar" rather than a double bond.

Ethane-1,2-disulfonyl chloride when boiled with water loses sulfur dioxide and forms an unsaturated acid. This unusual behavior is of considerable theoretical importance.

$$CH_2SO_2ClCH_2SO_2Cl + H_2O \rightarrow CH_2{=}CHSO_3H + 2HCl + SO_2$$

From an electronic viewpoint it may be explained on the assumption that the positively charged radical $CH_2SO_2ClCH_2SO_2^+$ occurring as an intermediate in the hydrolysis is unstable and decomposes as follows.



$$\begin{matrix} & \mathrm{O} & & \mathrm{H} & & \mathrm{H} & & \mathrm{O} & \\ \mathrm{Cl}: & \ddot{\mathrm{S}} & : & \ddot{\mathrm{C}} & : & \ddot{\mathrm{C}} & : & \ddot{\mathrm{S}} & :\mathrm{Cl} \\ & \ddot{\mathrm{O}} & & \ddot{\mathrm{H}} & & \ddot{\mathrm{H}} & & \ddot{\mathrm{O}} & \end{matrix} \rightarrow \left[\begin{matrix} & \mathrm{O} & & \mathrm{H} & & \mathrm{H} & & \mathrm{O} & \\ + & \ddot{\mathrm{S}} & : & \ddot{\mathrm{C}} & : & \ddot{\mathrm{C}} & : & \ddot{\mathrm{S}} & :\mathrm{Cl} \\ & \ddot{\mathrm{O}} & & \ddot{\mathrm{H}} & & \ddot{\mathrm{H}} & & \ddot{\mathrm{O}} & \end{matrix}\right] \rightarrow \left[\begin{matrix} & \mathrm{H} & & \mathrm{H} & & \mathrm{O} & \\ + & \ddot{\mathrm{C}} & : & \ddot{\mathrm{C}} & : & \ddot{\mathrm{S}} & :\mathrm{Cl} \\ & \ddot{\mathrm{H}} & & \ddot{\mathrm{H}} & & \ddot{\mathrm{O}} & \end{matrix}\right] + SO_2$$

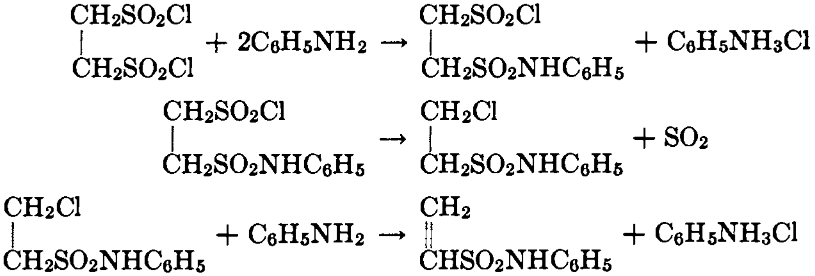
$$\left[\begin{matrix} & \mathrm{H} & & \mathrm{H} & & \mathrm{O} & \\ + & \ddot{\mathrm{C}} & : & \ddot{\mathrm{C}} & : & \ddot{\mathrm{S}} & :\mathrm{Cl} \\ & \ddot{\mathrm{H}} & & \ddot{\mathrm{H}} & & \ddot{\mathrm{O}} & \end{matrix}\right] \rightarrow \begin{matrix} \mathrm{H} & & \mathrm{H} & & \mathrm{O} & \\ \ddot{\mathrm{C}} & :: & \ddot{\mathrm{C}} & : & \ddot{\mathrm{S}} & :\mathrm{Cl} \\ \ddot{\mathrm{H}} & & & & \ddot{\mathrm{O}} & \end{matrix} \xrightarrow{H_2O} \begin{matrix} \mathrm{H} & & \mathrm{H} & & \mathrm{O} & \\ \ddot{\mathrm{C}} & :: & \ddot{\mathrm{C}} & : & \ddot{\mathrm{S}} & :\mathrm{OH} \\ \ddot{\mathrm{H}} & & & & \ddot{\mathrm{O}} & \end{matrix} + H^+ + Cl^-$$

Whether the second sulfonyl chloride group hydrolyzes before, simultaneously with, or after the formation of the double bond is uncertain. The fact that 2-bromoethane-1-sulfonyl chloride upon hydrolysis also yields some ethylenesulfonic acid indicates that various compounds having an electron-attracting group on the second carbon may behave similarly. As mentioned previously (see p. 110) even ethanesulfonyl chloride evolves a little sulfur dioxide when boiled with alcohol. The other products of this last reaction were not identified, but ethylene should be one of them.

Sulfur dioxide is also lost from ethane-1,2-disulfonyl chloride when treated with ammonia[454] or aniline. The reaction with aniline in ether solution has been studied in considerable detail[479b,483] and has

$$(CH_2SO_2Cl)_2 + 3NH_3 \rightarrow CH_2{=}CHSO_2NH_2 + SO_2 + 2NH_4Cl$$

been formulated as follows.

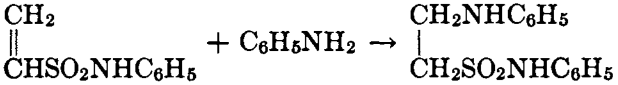


$$\begin{array}{l}CH_2SO_2Cl\\ |\\ CH_2SO_2Cl\end{array} + 2C_6H_5NH_2 \rightarrow \begin{array}{l}CH_2SO_2Cl\\ |\\ CH_2SO_2NHC_6H_5\end{array} + C_6H_5NH_3Cl$$

$$\begin{array}{l}CH_2SO_2Cl\\ |\\ CH_2SO_2NHC_6H_5\end{array} \rightarrow \begin{array}{l}CH_2Cl\\ |\\ CH_2SO_2NHC_6H_5\end{array} + SO_2$$

$$\begin{array}{l}CH_2Cl\\ |\\ CH_2SO_2NHC_6H_5\end{array} + C_6H_5NH_2 \rightarrow \begin{array}{l}CH_2\\ \|\\ CHSO_2NHC_6H_5\end{array} + C_6H_5NH_3Cl$$

This last reaction can also be effected by alcoholic potassium hydroxide. If an excess of aniline is present, further[454] reaction occurs.



$$\begin{array}{l}CH_2\\ \|\\ CHSO_2NHC_6H_5\end{array} + C_6H_5NH_2 \rightarrow \begin{array}{l}CH_2NHC_6H_5\\ |\\ CH_2SO_2NHC_6H_5\end{array}$$

Other aromatic amines including N-methylaniline and phenylhydrazine act similarly. Perhaps the most unusual feature of this reaction is the instability of the intermediate acid chloride, $C_6H_5NHSO_2CH_2$-CH_2SO_2Cl, which was not isolated but was reported[483b] to have a mustard-like odor.

Ethyl ethane-1,2-disulfonate[484] prepared from the silver salt and ethyl iodide is a solid, m.p. 77.5°. It reacts with ammonia normally with formation of ethylamine.

Higher Alkanedisulfonic Acids. Propane-1,2-disulfonic acid has been obtained by the sulfonation of butyric acid[435] or butyramide[435a] and by boiling propylene bromide with ammonium sulfite[440,483b] solution. Sodium sulfite gives chiefly propylene. The disulfonyl chloride reacts with aniline[479b] in the same manner as the lower homolog.

$$CH_3CH(SO_2Cl)CH_2SO_2Cl + 3C_6H_5NH_2 \rightarrow CH_3CH{=}CHSO_2NHC_6H_5 + SO_2 + 2C_6H_5NH_3Cl$$

Although "butylene" bromide was reported[483b] to give only the olefin, 2-methylpropane-1,2-disulfonic acid has been obtained by boiling isobutylene bromide with sodium sulfite solution.[485] The disulfonyl chloride was prepared and found to give a thiol on reduction with zinc and sulfuric acid.

Sodium sulfite reacts normally with trimethylene and higher polymethylene bromides[440,483b,486] and the resulting disulfonates give acid chlorides which react with ammonia to form the sulfonamides without loss of sulfur dioxide. Attempts to convert propane-1,3-disulfonyl chloride into various cyclic compounds[487] were unsuccessful. The aliphatic disulfonamides do not[460b,483] form N-chloro compounds analogous to Chloramine T.

ALKANEPOLYSULFONIC ACIDS

Methanetrisulfonic acid has been obtained in small amounts by sulfonation of calcium methyl sulfate[488] or methionic acid[489] with fuming sulfuric acid. Sulfonation of acetanilide[434,489,490] or acetamide with 35% fuming sulfuric acid gives as high as 57% yields of product isolated as the tripotassium salt. A small yield is also obtained from succinanilide under the same conditions.

When nitromethionic acid prepared from chloropicrin and potassium sulfite[491] is further treated with potassium sulfite the nitro group is replaced, a 67% yield of potassium methanetrisulfonate having been obtained.[489] Likewise diazomethionic acid[434,462,492] and thiosulfomethionic acid[463] are convertible into the trisulfonic acid as has already been discussed under methionic acid derivatives. Considering the yield and availability of starting materials, the sulfonation of acetamide or acetanilide seems to be the best method of preparation.

Methanetrisulfonic acid ($3.5H_2O$) melts at 156°. The anhydrous tripotassium salt is soluble in water at 25° to the extent of 1.2 g. per 100 g. of water.[489]

Heating methanetrisulfonic acid with excess bromine in aqueous solution at 150° gives the bromo compound[493] in 40% yield. By the action of potassium sulfite this bromo compound is reconverted into potassium methanetrisulfonate rather than into methanetetrasulfonic acid.

$$BrC(SO_3K)_3 + K_2SO_3 + H_2O \rightarrow HC(SO_3K)_3 + K_2SO_4 + HBr$$

Chlorination of potassium methanetrisulfonate in a manner similar to that used in the preparation of the bromo compound gives a 70% yield of pure product.[494] The pure acid is extremely soluble in water while the potassium salt is only slightly so (3.38 g. per 100 g. water at 25°). A number of other salts have been investigated in considerable detail.[495] The action of phosphorus pentachloride upon the free acid causes decomposition, sulfur dioxide being evolved.

ALKENESULFONIC ACIDS

The only unsaturated aliphatic sulfonic acid that has been thoroughly studied is ethylenesulfonic aid, which was investigated by Kohler.[496] By the action of potassium ethoxide in alcohol upon potassium 2-bromoethanesulfonate a very stable double salt of the unsaturated acid results.

$$2CH_2BrCH_2SO_3K + 2C_2H_5OK \rightarrow (CH_2{=}CHSO_3K)_2\cdot KBr + KBr + 2C_2H_5OH$$

This is also formed from vinyl bromide and potassium sulfite. Attempts to obtain the pure acid from this double salt have not been entirely successful; lead acetate does not precipitate the halogen, and concentrated sulfuric acid, although it removes the bromine, also adds to the double bond. The action of alkali upon sodium 2-chloroethanesulfonate yields ethylenesulfonic acid; apparently no double salt interferes here with isolation of the product.[497]

2-Bromoethanesulfonyl chloride gives as a minor product of its hydrolysis with water some ethylenesulfonic acid. When 2-bromoethanesulfonyl chloride reacts with the methyl ester of *dl*-leucylglycine a halogen free compound results.[498] This compound and the one from aniline are probably amides of ethylenesulfonic acid. A satisfactory method of preparing the unsaturated acid is to reflux ethane-1,2-disulfonyl chloride with five times its weight of water. In this case 80–90% of the sulfonyl chloride decomposes as indicated, hydrolysis to ethane-1,2-disulfonic acid accounting for the remainder. The reaction occurs in acetic acid containing some water with similar results but not in glacial acetic acid. In alcohol solution the yields of ethylenesulfonic acid are somewhat less and decrease with increasing molecular weight

$$CH_2BrCH_2SO_2Cl + H_2O \rightarrow CH_2{=}CHSO_3H + HBr + HCl$$

$$CH_2SO_2ClCH_2SO_2Cl + H_2O \rightarrow CH_2{=}CHSO_3H + 2HCl + SO_2$$

of the alcohol. Ether and ethyl chloride were noted as by-products in ethyl alcohol.

Ethane-1,2-disulfonyl chloride also reacts readily with sodium acetate in acetic acid solution. Sulfur dioxide and acetic anhydride were noted among the reaction products besides sodium ethylenesulfonate and sodium ethanedisulfonate. Pyrolysis of 2-bromoethanesulfonyl chloride under a pressure of one meter of mercury (in excess of atmospheric) gives a small yield of ethylenesulfonyl chloride which may be hydrolyzed to the acid.

$$CH_2BrCH_2SO_2Cl \rightarrow CH_2{=}CHSO_2Cl + HBr$$

Although isethionic acid or its salts could not be dehydrated satisfactorily to the unsaturated acid, the acetate decomposes readily at 185° with evolution of acetic acid.

$$CH_3COOCH_2CH_2SO_3K \rightarrow CH_3COOH + CH_2{=}CHSO_3K$$

Ethionic acid has also been reported to give the olefinic acid[499] when heated.

$$CH_2(OSO_3Na)CH_2SO_3Na \rightarrow CH_2{=}CHSO_3Na + NaHSO_4$$

Heating 1,2-dibromoethanesulfonic acid or 2-bromo-1-chloroethanesulfonic acid with zinc gives a nearly quantitative yield of ethylenesulfonic acid.

$$Zn + CH_2ClCHBrSO_3H \rightarrow CH_2{=}CHSO_3K + ZnClBr$$

Ethylenesulfonic acid is readily attacked by oxidizing agents. Even ammoniacal silver nitrate decomposes it completely. It may be titrated quantitatively with potassium permanganate in acid solution.

$$5C_2H_3SO_3H + 12KMnO_4 + 13H_2SO_4 \rightarrow 10CO_2 + 23H_2O + 12MnSO_4 + 6K_2SO_4$$

All attempts to stop the oxidation at an intermediate stage were unsuccessful. Reduction to ethanesulfonic acid occurs with hydriodic acid and phosphorus at 170°, but no other common reducing agent has any effect. Catalytic reduction has not been investigated.

Addition reactions occur readily with ethylenesulfonic acid. Water adds at 150° to give isethionic acid. Hydrochloric and hydrobromic acids add to give products of analogous structure.

$$CH_2{=}CHSO_3K + HX \rightarrow XCH_2CH_2SO_3K$$

Bromine, however, reacts by substitution rather than addition.

$$CH_2{=}CHSO_3K + Br_2 \rightarrow CH_2{=}CBrSO_3K + HBr$$

The dibromide is not an intermediate product in this reaction as it can be prepared by adding hydrogen bromide to bromoethylenesulfonic acid at a higher temperature and is stable in water solution. The position of the bromine in the unsaturated acid is indicated by the addition of water and reduction to isethionic acid.

$$CH_2{=}CBrSO_3H + H_2O \rightarrow CH_2OHCHBrSO_3H$$

$$CH_2OHCHBrSO_3H \xrightarrow{NaHg} CH_2OHCH_2SO_3H$$

Sodium bisulfite adds readily in aqueous solution to produce ethane-1,2-disulfonic acid.

$$CH_2{=}CHSO_3Na + NaHSO_3 \rightarrow CH_2SO_3NaCH_2SO_3Na$$

1-Bromoethylenesulfonic acid has a number of interesting properties.[410c] Although boiling a 6% solution of the free acid causes no appreciable decomposition, attempts to prepare the pure acid by concentration of the aqueous solution cause the liberation of sulfur dioxide and hydrogen bromide. Toward oxidizing agents the acid behaves similarly to ethylenesulfonic acid. By reduction with zinc or magnesium, in acid solution, the bromine is readily replaced by hydrogen, the sulfonic acid group being unaffected.

$$CH_2{=}CBrSO_3H + Zn + HCl \rightarrow CH_2{=}CHSO_3H + ZnClBr$$

Water adds readily to give 2-hydroxy-1-bromoethanesulfonic acid. Halogen acids likewise add easily but the free halogens or hypochlorous acid cause complete oxidation. Sulfuric acid below 80° gives bromoethionic acid.

$$CH_2{=}CBrSO_3H + H_2SO_4 \rightarrow CH_2(OSO_3H)CHBrSO_3H$$

At 125° another somewhat unstable acid results which apparently contains three sulfo groups, one of them corresponding in behavior to an aldehyde bisulfite addition product. It was isolated only as the barium salt.

$$CH_2{=}CBrSO_3H + 2H_2SO_4 \rightarrow CHOH(SO_3H)CBr(SO_3H)_2 + H_2O$$

Heating a salt of bromoethylenesulfonic acid in aqueous alkali leads to removal of both the halogen and sulfur. This is interesting as the

$$2CH_2{=}CBrSO_3H + 3Ba(OH)_2 \rightarrow$$
$$2BaSO_3 + BaBr_2 + (CH_2{=}C{=}O) + H_2O$$

primary hydrolysis product should be ketene or a hydration product. Actually a polymeric gummy substance results.

The unsaturated sulfonic acid formed in the reaction of allyl iodide with potassium sulfite[500a] or ethyl sulfite in alkaline solution[54] was isolated only as a complex double salt. Allyl chloride and sodium sulfite react normally. The free sulfonic acid and derivatives of it were found to be unstable. Heating allyl alcohol to 100° with a solution of ammonium sulfite[501] gives an unsaturated sulfonic acid salt which was believed to have the same structure as the acid obtained from allyl iodide. This was not clearly demonstrated, however. The reactions may be those shown in the equations.

$$4(C_2H_5)_2SO_3 + 4CH_2{=}CHCH_2I + 8KOH \rightarrow (CH_2{=}CHCH_2SO_3K)_4 \cdot KI + 3KI + 8C_2H_5OH$$

$$HOCH_2CH{=}CH_2 + NH_4HSO_3 \rightarrow HOCH_2CH_2CH_2SO_3NH_4$$

$$HOCH_2CH_2CH_2SO_3NH_4 \xrightarrow{\Delta} CH_2{=}CHCH_2SO_3NH_4 + H_2O$$

Although propene-1-sulfonic acid has not been studied the corresponding anilide results from the action of aniline upon propane-1,2-disulfonyl chloride.[502a] The action of sodium sulfite upon vicinal dihalides at a high temperature yields unsaturated sulfonic acids.[502b] The oxidation of allyl-type mercaptans also gives olefinic sulfonic acids.[500b]

$$CH_3CHSO_2ClCH_2SO_2Cl + 3C_6H_5NH_2 \rightarrow CH_3CH{=}CHSO_2NHC_6H_5 + 2C_6H_5NH_3Cl + SO_2$$

Recently it has been shown that the action of dioxane sulfotrioxide upon excess isobutylene gives chiefly 2-methylpropene-3-sulfonic acid.

$$CH_2{=}C(CH_3)_2 + O(CH_2CH_2)_2OSO_3 \rightarrow CH_2{=}C(CH_3)CH_2SO_3H + O(CH_2CH_2)_2O$$

A small amount of 2-hydroxy-2-methylpropanesulfonic acid accompanies the main product.[503] The same unsaturated acid was obtained by refluxing methallyl chloride with sodium sulfite. Condensation of the sodium sulfonate or the free acid with aromatic hydrocarbons occurs in the presence of concentrated sulfuric acid or boron trifluoride. The products show some promise as detergents and wetting agents. Similar condensations occur with phenols and aromatic ethers.

$$C_4H_9C_6H_5 + CH_2{=}C(CH_3)CH_2SO_3H \rightarrow C_4H_9C_6H_4C(CH_3)_2CH_2SO_3H$$

The sulfonation of isobutylene with chlorosulfonic acid in dioxane gives, in addition to the olefinic acid already mentioned, *tert*-butyl chloride and a diïsobutylenesulfonic acid.

The conversion of olefins into sulfonic acids by sulfonation with the addition products of ether, ethyl sulfide, ethyl acetate, thioxane, pyridine, or diethylene dioxide (dioxane) or with sodium chlorosulfonate has been mentioned in the patent literature.[504] Branched-chain olefins are reported to yield sulfonic acids when treated with chlorosulfonic acid.[505] Definite structures for these products are lacking, but some unsaturated sulfonic acids may result. The same may be said of the products obtained in acetic acid or anhydride solutions.[506] The sulfonation of tertiary alcohols with chlorosulfonic acid [507] or sulfuric acid in acetic anhydride [508] gives sulfonic acids which may contain unsaturated groups. It has been shown that cholestenone under these conditions [509] gives an 80–85% yield of an unsaturated acid.

1-Hexadecene has been reported [510] to react with sulfur trioxide to form an unsaturated acid of unknown structure that was practically insoluble in cold water; the potassium salt was slightly soluble in boiling water. Rubber reacts with oleum or chlorosulfonic acid in the presence of an ether or ester [511] to give water-soluble sulfonic acids.

Quilico [512] has discovered a method of obtaining sulfonic acids from aromatic compounds with an unsaturated side chain. Styrene reacts with aminosulfonic acid at 150° according to the equation,

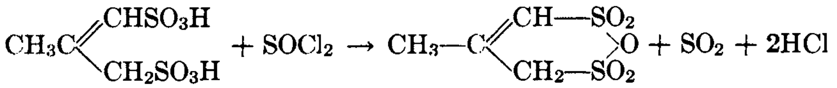
$$C_6H_5CH{=}CH_2 + NH_2SO_3H \rightarrow C_6H_5CH{=}CHSO_3NH_4$$

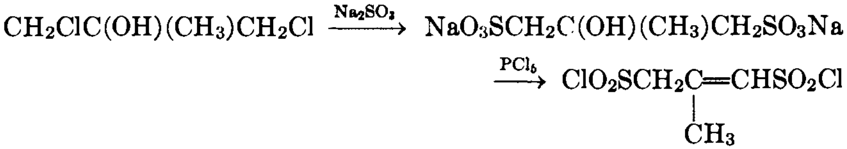
The correctness of the assigned structure was based upon the oxidation to benzoic acid with permanganate and the conversion to sodium cinnamate with sodium formate. Anethole, apiol, and isosafrole yield sulfonic acids with similar properties.

Several disulfonic acids containing an olefinic group have been prepared. Sodium 2-butene-1,4-disulfonate,[513] probably obtained from the bromide, adds methylamine as shown.

$$NaO_3SCH_2CH{=}CHCH_2SO_3Na + CH_3NH_2 \rightarrow NaO_3SCH_2CH(NHCH_3)(CH_2)_2SO_3Na$$

The sulfonation of isobutylene by passing the gaseous hydrocarbon into an ethylene chloride solution of dioxane sulfotrioxide [503] gives the 1,3-disulfonic acid as a dioxane salt. The acid can be converted into the anhydride with thionyl chloride and into the chloride with phosphorus pentachloride. Anhydride formation suggests but does not prove that it is the *cis* compound. The same sulfonyl chloride was obtained from the dichlorohydrin by the following steps.

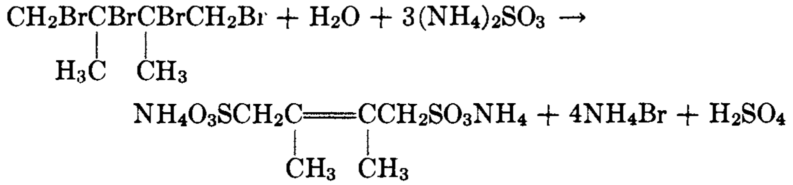




$$CH_2ClC(OH)(CH_3)CH_2Cl \xrightarrow{Na_2SO_3} NaO_3SCH_2C(OH)(CH_3)CH_2SO_3Na \xrightarrow{PCl_5} ClO_2SCH_2\underset{\displaystyle CH_3}{C}{=}CHSO_2Cl$$

Treating an aqueous solution of the barium sulfonate with bromine water converted nearly half of the sulfur into barium sulfate. The other products of this reaction have not been investigated.

An unsaturated disulfonic acid has been obtained by the action of ammonium sulfite upon 2,3-dimethyl-1,2,3,4-tetrabromobutane.[514] The barium salt was isolated in 80% yields.



$$CH_2Br\underset{\displaystyle H_3C}{C}Br\underset{\displaystyle CH_3}{C}BrCH_2Br + H_2O + 3(NH_4)_2SO_3 \rightarrow$$

$$NH_4O_3SCH_2\underset{\displaystyle CH_3}{C}{=}\underset{\displaystyle CH_3}{C}CH_2SO_3NH_4 + 4NH_4Br + H_2SO_4$$

There is then considerable diversity in the reaction of polybromo compounds with sulfites. Ethylene bromide and 1,2,3-tribromopropane give the corresponding sulfonic acid salts; 2,3-dibromobutane gives a mixture of the isomeric hydroxysulfonic acids while the compounds containing a tertiary halogen form unsaturated products. The behavior of other di- and tribromides should be of considerable interest.

Unsaturated sulfocarboxylic acids have been mentioned elsewhere (see pp. 147 and 157).

One sulfonic acid derived from an alkylacetylene is on record. Tetradecylacetylene upon standing with concentrated sulfuric acid[515] is believed to give the compound indicated.

$$C_{14}H_{29}C{\equiv}CH + H_2SO_4 \rightarrow C_{14}H_{29}C{\equiv}CSO_3H + H_2O$$

One might expect addition at the triple bond rather than sulfonation in this reaction. Since the only evidence given for the structure was an analysis, further study of this reaction is desirable.

REFERENCES

1. Worstall, *J. Am. Chem. Soc.*, **21**, 246 (1899).

2. Orndorff and Young, *Am. Chem. J.*, **15**, 261 (1893).

3. Hurd and Pilgrim, Northwestern University, private communication.

4. Worstall, *Am. Chem. J.*, **20**, 664 (1898).

5. Burkhardt, *J. Chem. Soc.*, 2387 (1930).

6. Menshutkin and Wolf, *C.A.*, **22**, 2744 (1928).

7. Aschan, *Chem.-Ztg.*, **29**, 747 (1905).

8. Istrati and Michelson, *Chem. Zentr.*, I, 1447 (1904).

9. Aschan, *Ber.*, **31**, 1801 (1898).

10*a*. Young, *J. Chem. Soc.*, **75**, 172 (1899). *b*. Shepard and Henne, *Ind. Eng. Chem.*, **22**, 356 (1930); Shepard, Henne, and Midgely, *J. Am. Chem. Soc.*, **53**, 1948 (1931).

11*a*. Fox, Henke, and Reed, U. S. pat., 2,228,598, *C.A.*, **35**, 3011 (1941); Reed, U. S. pat., 2,239,974, *C.A.*, **35**, 4881 (1941); Orthner, Balle, and Horst, U. S. pat., 2,225,960, *C.A.*, **35**, 2248 (1941); British pat., 516,214, *C.A.*, **35**, 5911 (1941). *b*. Kharasch and Read, *J. Am. Chem. Soc.*, **61**, 3091 (1939).

12*a*. Miller, *Ann.*, **189**, 340 (1877). *b*. Kolker and Lapworth, *J. Chem. Soc.*, **127**, 307 (1925). *c*. Ashworth and Burkhardt, *ibid.*, 1791 (1928). *d*. Kharasch, May, and Mayo, *J. Org. Chem.*, **3**, 175 (1938). *e*. Ufer and Hecht, U. S. pat., 2,140,569, *C.A.*, **33**, 2730 (1939). *f*. Kharasch and Read, *J. Am. Chem. Soc.*, **61**, 3092 (1939).

13. Lowig and Weidmann, *Pogg. Ann.*, **47**, 153 (1839); **49**, 329 (1840); Kopp, *Ann.*, **35**, 346 (1840).

14. Duguet, *Chem. Zentr.*, I, 854 (1902); *Rec. trav. chim.*, **21**, 77 (1902).

15. Claus, *Ber.*, **5**, 660 (1872); **8**, 532 (1875).

16*a*. Grabowski, *Ann.*, **175**, 344 (1875). *b*. Vivian and Reid, *J. Am. Chem. Soc.*, **57**, 2559 (1935). *c*. Duguet, *Chem. Zentr.*, I, 1530 (1906).

17. Levene and Mikeska, *J. Biol. Chem.*, **63**, 85 (1925).

18. Mylius, *Ber.*, **5**, 978 (1872); Pauly, *Ber.*, **10**, 942 (1877).

19. Wagner and Reid, *J. Am. Chem. Soc.*, **53**, 3411 (1931).

20. Erdmann and Gerathewohl, *J. prakt. Chem.*, [1] **34**, 447 (1845); Hofmann, *Ann.*, **69**, 227 (1849); Medlock, *Ann.*, **69**, 224 (1849).

21. Pelouze and Cahours, *Ann.*, **127**, 192 (1863).

22*a*. Levene and Mikeska, *J. Biol. Chem.*, **65**, 515 (1925). *b*. Levene and Mikeska, *ibid.*, **59**, 473 (1924).

23. Werntz, U. S. pat., 2,142,162, *C.A.*, **33**, 3031 (1939).

24*a*. Noller and Gordon, *J. Am. Chem. Soc.*, **55**, 1090 (1933). *b*. McBain and Williams, *ibid.*, **55**, 2250 (1933).

25. Murray, *J. Chem. Soc.*, 739 (1933).

26. Reychler, *Bull. soc. chim. Belg.*, **27**, 110, 217, 300 (1913); *C.A.*, **8**, 1105 (1914).

27. Franchimont and Klobbie, *Ber.*, **5 Ref.**, 275 (1872).

28*a*. Collin, Hilditch, Marsh, and McLeod, *J. Soc. Chem. Ind.*, **52**, 272 (1933). *b*. Norris, *J. Chem. Soc.*, **121**, 2161 (1922). *c*. Flaschentrager and

Wannschaff, *Ber.*, **67B**, 1121 (1934). *d.* See also Schirm, U. S. pat., 1,966,187, *C.A.*, 28, 5698 (1934).

29. Autenrieth, *Ann.*, **259**, 363 (1892).
30. Backer, *Rec. trav. chim.*, **54**, 215 (1935).
31. Muspratt, *Ann.*, **65**, 251 (1848); Medlock, *Ann.*, **69**, 224 (1849); Bogert, *J. Am. Chem. Soc.*, **25**, 289 (1903).
32. Hunter and Sorenson, *ibid.*, **54**, 3365 (1932).
33. Oechsner De Coninck, *Compt. rend.*, **126**, 838 (1898).
34. Fichter and Wenk, *Ber.*, **45**, 1373 (1912); Fichter and Schonlau, *Ber.*, **48**, 1153 (1915).
35*a*. Spring and Winssinger, *Bull. soc. chim.*, [2] **49**, 72 (1888). *b.* Johnson and Sprague, *J. Am. Chem. Soc.*, **58**, 1348 (1936); **59**, 1837, 2439 (1937). *c.* Johnson and Douglass, *ibid.*, **61**, 2548 (1939). *d.* Douglass and Johnson, *ibid.*, **60**, 1486 (1938). *e.* Johnson, U. S. pats., 2,146,744 and 2,147,346, *C.A.*, **33**, 3815 (1939). *f.* Bruson and Eastes, U. S. pat., 2,142,934, *C.A.*, **33**, 3031 (1939). *g.* Johnson, U. S. pat., 2,174,856, *C.A.*, **34**, 778 (1940). *h. Proc. Natl. Acad. Sci. U. S.*, **25**, 448 (1939).
36*a*. Graebe, *Ann.*, **146**, 37 (1868). *b.* Strecker, *Ann.*, **148**, 90 (1868). *c.* Bender, *Ann.*, **148**, 96 (1868). *d.* Collman, *Ann.*, **148**, 101 (1868). *e.* Stuffer, *Ber.*, **23**, 3228 (1890).
37*a*. Duguet, *Chem. Zentr.*, I, 1530 (1906). *b.* See also Davidson, U. S. pat., 2,053,424, *C.A.*, **30**, 7125 (1936); British pat., 433,312, *C.A.*, **30**, 491 (1936). *c.* Zuffanti, *J. Am. Chem. Soc.*, **62**, 1044 (1940).
38*a*. Hemilian, *Ann.*, **168**, 146 (1873). *b.* Latimer and Bost, *J. Org. Chem.*, **5**, 24 (1940).
39*a*. Reed and Tartar, *J. Am. Chem. Soc.*, **57**, 570 (1935); recent patent citations are made in this reference. *b.* See also Pilat and Turkiewicz, *Ber.*, **72B**, 1527 (1939).
40. For the preparation of phenylmethanesulfonic acid from benzyl chloride and a sulfite see p. 114.
41. Böeseken and Van Oeckenburg, *Rec. trav. chim.*, **33**, 319 (1914).
42. Borsche and Lange, *Ber.*, **38**, 2766 (1905); **39**, 392 (1906); **40**, 2220 (1907).
43. Latimer and Bost, *J. Am. Chem. Soc.*, **59**, 2500 (1937).
44*a*. Noller and Gordon, *ibid.*, **55**, 1090 (1933). *b.* Levene, Rothen, and Kuna, *J. Biol. Chem.*, **121**, 747 (1937).
45. Hunter and Sorenson, *J. Am. Chem. Soc.*, **54**, 3364 (1932).
46. Cherbuliez and Schnauder, *Helv. Chim. Acta*, 6, 249 (1923).
47. Oddo, *Atti. accad. Lincei*, [5] **14**, I, 169 (1905); *Gazz. chim. ital.*, **35**, II, 136 (1905).
48. Davies and Dick, *J. Chem. Soc.*, **483** (1932).
49. Spring and Winssinger, *Ber.*, **15**, 445 (1882); **16**, 326 (1883).
50. Spring and Winssinger, *Ber.*, **17**, 537 (1887).
51. Spring and Winssinger, *Bull. soc. chim.*, [2] **49**, 72 (1888).
52. Mandel and Neuberg, *Biochem. Z.*, **71**, 180 (1915).
53. Kolbe, *Ann.*, **54**, 174 (1845).
54. Arbusow and Pischtschmimuka, *J. Russ. Phys.-Chem. Soc.*, **41**, 451 (1909); *Chem. Zentr.*, II, 685 (1909).
55. Arbusow and Kartaschow, *J. Russ. Phys.-Chem. Soc.*, **46**, 284 (1914); *Chem. Zentr.*, I, 2156 (1914).
56. Marvel. Helfrick. and Belsley, *J. Am. Chem. Soc.*, **51**, 1272 (1929).

57. Mörner, *Z. physiol. Chem.*, **93**, 190 (1915); **101**, 18 (1918).

58. Schneider, *Ann.*, **375**, 234 (1910).

59*a*. Billeter, *Ber.*, **38**, 2019 (1905). *b*. Berthoud, *Helv. Chim. Acta*, **12**, 859 (1929).

60. Berthelot, *Jahresbericht*, 336 (1869).

61. Fichter and Lichtenhohn, *Ber.*, **48**, 1961 (1915).

62*a*. Carius, *Ann.*, **114**, 143 (1860); Helferich and Gnüchtel, *Ber.*, **71**, 712 (1938); Helferich and Mittag, *Ber.*, **71**, 1480 (1938). *b*. Schroeter, German pat., 634,687, *C.A.*, **31**, 710 (1937).

63. McGowan, *J. prakt. Chem.*, [2] **30**, 283 (1884).

64. Böeseken and Van Oeckenburg, *Rec. trav. chim.*, **33**, 320 (1914).

65. Duguet, *ibid.*, **21**, 76 (1902).

66*a*. Dutt, *J. Chem. Soc.*, **125**, 1463 (1924). *b*. Helferich and Grünert, *Ann.*, **545**, 178 (1940).

67*a*. Sekera and Marvel, *J. Am. Chem. Soc.*, **55**, 345 (1933). *b*. Helferich, Dressel and Griebel, *J. prakt. Chem.*, **153**, 285 (1939); Helferich and Jochinke, *Ber.*, **73B**, 1049 (1940); **74B**, 719 (1941).

68. Kolbe, *Ann.*, **64**, 164 (1845).

69*a*. Demars, *Bull. sci. pharmacol.*, **29**, 425 (1922). *b*. Steindorff, Daimler, and Platz, German pat., 657,357, *C.A.*, **32**, 4252 (1938); see also 652,410, *C.A.*, **32**, 1814 (1938). *c*. Johnson and Douglass, *J. Am. Chem. Soc.*, **63**, 1571 (1941). *d*. Kostsova, *J. Gen. Chem.* (*U.S.S.R.*), **11**, 63 (1941).

70. McGowan, *J. prakt. Chem.*, [2] **30**, 299 (1884).

71. Rathke, *Ann.*, **167**, 195 (1873); Schecter and Haller, *J. Am. Chem. Soc.*, **63**, 1764 (1941).

72. Battegay and Kern, *Bull. soc. chim.*, **41**, 34 (1927); Durand and Naves, *ibid.*, **41**, 632 (1927).

73. Hantzsch, *Ann.*, **296**, 86 (1897).

74. Backer, *Rec. trav. chim.*, **44**, 1056 (1925).

75*a*. Andreasch, *Monatsh.*, **7**, 167 (1886). *b*. Allardt, German pat., 575,678, *C.A.*, **27**, 4880 (1933).

76. Binz and Hughes, *Arch. klin. Chirurgie*, **171**, No. 1 (1932).

77*a*. Aurisicchio, *Industria chimica*, **7**, 714 (1932); *C.A.*, **27**, 2420 (1933). *b*. Soteria Chemische Fabrik A.-G., British pat., 369,473, *C.A.*, **27**, 2161 (1933). *c*. Allardt, U. S. pat., 1,867,793, *C.A.*, **26**, 5105 (1932). *d*. Ossenbeck, Tietze, and Hecht, German pat., 532,766, *C.A.*, **26**, 480 (1932). *e*. Klos, German pat., 581,818, *C.A.*, **28**, 1056 (1934).

78. Ossenbeck, Tietze, and Hecht, German pat., 535,652; French pat., 708,270, *C.A.*, **26**, 1301 (1932).

79. Ossenbeck, Tietze, and Hecht, British pat., 353,477, *C.A.*, **26**, 3517 (1932); French pat., 40,169, *C.A.*, **27**, 735 (1933); German pat., 551,145, *C.A.*, **26**, 4828 (1932).

80. Tietze, Ossenbeck, and Hecht, German pat., 562,501, *C.A.*, **27**, 1010 (1933).

81. Backer, *Rec. trav. chim.*, **45**, 830 (1926).

82. Allardt, German pat., 546,354, *C.A.*, **26**, 3265 (1932); see also German pat., 575,678, *C.A.*, **27**, 4880 (1933).

83. Binz and Hughes, *Ber.*, **68B**, 1513 (1935); Binz, British pat., 451,034, *C.A.*, **31**, 116 (1937); German pat., 635,242, *C.A.*, **31**, 116 (1937).

84. Pope and Read, *J. Chem. Soc.*, **93**, 797 (1908); **105**, 811 (1914).

85. Read and McMath, *ibid.*, **127**, 1572 (1925).

86. Read and McMath, *ibid.*, **2723** (1932).
87. Rosenheim and Liebknecht, *Ber.*, **31**, **407** (1898); Arbusow, *Ber.*, **42**, **4691** (1909); Baggesgaard-Rasmussen, *Ber.*, **52**, 1069 (1919).
88. Mayer, *Ber.*, **23**, 909 (1890); German pat., 55,007, *Frdl.*, **2**, 552.
89. Rosenheim and Sarow, *Ber.*, **38**, 1302 (1905).
90. Kohler, *Am. Chem. J.*, **20**, 680 (1898).
91. Berthelot, *Compt. rend.*, **69**, 563 (1870).
92. Gerhardt and Chancel, *Jahresbericht*, 434 (1852).
93. Carius, *Ann.*, **114**, 142 (1860).
94. Autenrieth, *Ann.*, **259**, 364 (1890).
95. Voight, *Ann.*, **119**, 152 (1861).
96. Otto, *Ber.*, **15**, 122 (1882).
97. James, *J. prakt. Chem.*, [2] **26**, 384 (1882); Duguet, *Rec. trav. chim.*, **21**, **46** (1902); Franchimont, *Chem. Zentr.*, II, 1960 (1913).
98. Carius, *J. prakt. Chem.*, [2] **2**, 267 (1870).
99. Kurbotow, *Ann.*, **173**, 7 (1874).
100. Nasini, *Ber.*, **15**, 2884 (1882).
101. Walden and Swinne, *Z. physik. Chem.*, **79**, 725 (1912).
102. Walden, *ibid.*, **70**, 578 (1910); **54**, 174 (1906); **55**, 225 (1906).
103. Schaefer, *Z. anorg. allgem. Chem.*, **104**, 239 (1916); *Z. Elektrochem.*, **21**, 1, 184 (1915).
104. Ferns and Lapworth, *J. Chem. Soc.*, **101**, 284 (1917).
105. Strecker, *Ber.*, **43**, 1136 (1910).
106. Autenrieth and Bernheim, *Ber.*, **37**, 3803 (1904).
107. Fischer, *Z. physik. Chem.*, **65**, 67 (1909).
108. Ernst and Nicodemus, U. S. pat., 1,888,794, *C.A.*, **27**, 1641 (1933); British pat., 360,558, *C.A.*, **27**, 1006 (1933).
109. Marvel and Sparberg, *Org. Syntheses*, **10**, 96 (1930), John Wiley & Sons, New York.
110. Kohler, *Am. Chem. J.*, **20**, 690 (1898).
111. Kolbe, *Ann.*, **122**, 38 (1862).
112*a*. Kohler, *Am. Chem. J.*, **19**, 737 (1897). *b. Ibid.*, **21**, 361 (1899).
113. James, *J. Chem. Soc.*, **47**, 365 (1885); *J. prakt. Chem.*, [2] **31**, 411 (1885).
114. Stodel, *Z. Chem.*, 272 (1868).
115. Bleicher, *Z. Kryst. Min.*, **51**, 502 (1912).
116. Kind, *Z. Chem.*, 165 (1869); Bunte, *Ann.*, **170**, 317 (1873).
117. Müller and Raudenbusch, *Ber.*, **64B**, 94 (1931).
118*a*. J. W. McBain and Betz, *J. Am. Chem. Soc.*, **57**, 1905, 1909, 1913 (1935). *b*. J. W. McBain, *ibid.*, **57**, 1917 (1935). *c*. E. L. McBain, Dye, and Johnston, *ibid.*, **61**, **3210** (1939). *d*. E. L. McBain, *Proc. Roy. Soc. (London)*, **170A**, 415 (1939). *e*. Reed and Tartar, *J. Am. Chem. Soc.*, **58**, 322 (1936). *f*. Houlton and Tartar, *ibid.*, **60**, 544 (1938). *g*. Tartar and Wright, *ibid.*, **61**, 539, **544** (1939). *h*. Wright, Abbott, Sivertz, and Tartar, *ibid.*, **61**, 549 (1939). *i*. McBain and Woo, *J. Phys. Chem.*, **42**, 1099 (1938). *j*. Kimura, Nakano, and Taniguti, *J. Soc. Chem. Ind. Japan*, **42**, Suppl. binding **121** (1939); *C.A.*, **33**, **7165** (1939). *k*. J. W. McBain and Wood, *Proc. Roy. Soc. (London)*, **174A**, 286 (1940).
119*a*. Böhler, *Ann.*, **154**, 50 (1869). *b*. Mohr, *Ann.*, **221**, **216** (1883). *c*. Fromm and de Seixas Palma, *Ber.*, **39**, 3312 (1906). *d*. Johnson and Ambler, *J. Am. Chem. Soc.*, **36**, 381 (1914).

120. Fromm and de Seixas Palma, *Ber.*, **39**, 3319 (1906).

121. Barbaglia, *Ber.*, **5**, 270, 687 (1872).

122. Krekeler, *Ber.*, **19**, 2625 (1886).

123. Bonomi da Monte and Zoso, *Gazz. chim. ital.*, **27**, II, 472 (1897).

124. Otto and Luders, *Ber.*, **13**, 1288 (1880).

125. Limpricht and von Pechmann, *Ber.*, **6**, 534 (1873).

126. Wedekind and Schenk, *Ber.*, **44**, 199 (1911).

127a. Fischer, *Ber.*, **48**, 101 (1915). *b.* Marvel and Gillespie, *J. Am. Chem. Soc.*, **48**, 2943 (1926).

128. Farbw. vorm. Meister, Lucius, and Brüning, German pat., 146,946, *Chem. Zentr.*, I, 66 (1904).

129. Kalle and Co., German pat., 141,783, *Chem. Zentr.*, I, 1324 (1903); Farbw. vorm. Meister, Lucius, and Brüning, German pat., 150,366, *ibid.*, I, 1307 (1904).

130*a*. Jackson and White, *Am. Chem. J.*, **2**, 160 (1880). *b.* Farbw. vorm. Meister, Lucius, and Brüning, German pat., 154,493, *Chem. Zentr.*, II, 1557 (1904).

131. Badische Anilin.- und Sodafabrik, German pat., 134,988, *ibid.*, II, 1372 (1902).

132. Jackson and Hartshorn, *Am. Chem. J.*, **5**, 264 (1883).

133. Weiss and Reiter, *Ann.*, **355**, 175 (1907); Bottomley and Robinson, *J. Chem. Soc.*, 2785 (1927); Grotowsky, German pat., 607,535, *C.A.*, **29**, 4028 (1935).

134. Fischer, German pat., 48,722, *Frdl.*, **2**, 98; Marckwald and Frahne, *Ber.*, **31**, 1855 (1898); Purgotti and Monti, *Gazz. chim. ital.*, **30**, II, 247 (1900); Weiss and Reiter, *Ann.*, **355**, 189 (1907).

135. Farbw. vorm. Meister, Lucius, and Brüning, German pat., 229,873, *Chem. Zentr.*, I, 358 (1911).

136. Bonomi da Monte and Zoso, *Gazz. chim. ital.*, **27**, II, 469 (1897).

137. Evans, Mabbott, and Turner, *J. Chem. Soc.*, 1159 (1927).

138. Schenk, *Pharm. Ztg.*, **54**, 725 (1909); *C.A.*, **5**, 885 (1911).

139*a*. Staudinger and Pfenninger, *Ber.*, 49, 1950 (1916). *b.* I. G. Farbenind. A.-G., French pat., 780,027, *C.A.*, **29**, 5864 (1935).

140. Baeyer and Villiger, *Ber.*, **35**, 3016 (1902); Mothurf, *Ber.*, **37**, 3158 (1904).

141. Baeyer and Villiger, *Ber.*, **36**, 2793 (1903).

142. Schiff, *Compt. rend.*, **64**, 182 (1866); Hantzsch and Osswald, *Ber.*, **33**, 308 (1900); Durrschnabel and Weil, *Ber.*, **38**, 3495 (1905).

143. Kastle, *Am. Chem. J.*, **42**, 296 (1909).

144*a*. Wieland and Schewing, *Ber.*, **54**, 2527 (1921). *b.* Rumpf, *Ann. chim.*, [11] **3**, 329 (1935).

145*a*. Backer and Mulder, *Rec. trav. chim.*, **52**, 454 (1933). *b.* Rumpf, *Bull. soc. chim.*, [5] **6**, 871 (1938); Copper salts of aminomethanesulfonic acid are described by Meyer and Taube, *Z. anorg. allgem. Chem.*, **227**, 425 (1936).

146*a*. Backer and Mulder, *Rec. trav. chim.*, **53**, 1120 (1934); for earlier work see Tilley, *Ann.*, **67**, 105 (1848); Redtenbacher, *Ann.*, **65**, 37 (1848). *b.* Schroeter, *Ber.*, **56B**, 1038 (1933). *c.* Guenther and Haussmann, U. S. pat., 1,932,177, *C.A.*, **28**, 671 (1934). *d.* McIlwain, *J. Chem. Soc.*, 75 (1941). *e.* Orthner, Balle, Horst, and Schild, U. S. pat., 2,243,437, *C.A.*, **35**, 5600 (1941).

147*a*. Bucherer and Schwalbe, *Ber.*, **39**, 2798 (1906); Knoevenagel, German pat., 153,193, *Chem. Zentr.*, II, 575 (1904). *b*. Abelin and Perelstein, *Ann.*, **411**, 216 (1916). *c*. Eibner, *Ann.*, **315**, 89 (1901); Mayer, *Gazz. chim. ital.*, **42**, I, 50 (1912); Speroni, *ibid.*, **33**, I, 113 (1903). *d*. Schiff, *Ann.*, 210, 123 (1881); Farbw. vorm. Meister, Lucius, and Brüning, Bockmuhl and Schwartz, British pat., 243,925, *C.A.*, **21**, 592 (1927); British pat., 164,002, *C.A.*, **16**, 141 (1922). *e*. Henry and Gray, British pat., 491,265, *C.A.*, **33**, 1104 (1939). *f*. Whitby, *Lancet*, I, 1517 (1937).

148. Tiedeman and Gmelin, *Pogg. Ann.*, 9, 327 (1827).

149. Demarcay, *Ann.*, **27**, 286 (1838); Pelouze and Dumas, *Ann.*, **27**, 292 (1838); Redtenbacher, *Ann.*, **57**, 170 (1846); **65**, 37 (1848).

150. Hammersten, *Z. physiol. Chem.*, **32**, 456 (1901); **43**, 127 (1904).

151. Tauber, *Beitr. Phys. Path.*, **4**, 324 (1903); Bang, *ibid.*, **7**, 148 (1905); Tanaka, *Z. physiol. Chem.*, **220**, 39 (1933).

152. Schmidt and Watson, *J. Biol. Chem.*, **33**, 499 (1918).

153. Kermack and Slater, *Biochem. J.*, **21**, 1065 (1927).

154. Bergmann, *Beitr. Phys. Path.*, **4**, 192 (1903); Wohlgemuth, *Zeit. physiol. Chem.*, **40**, 81 (1904); Loeper, Garcin, Lesure, and Tonnet, *Bull. soc. chim. biol.*, **10**, 316 (1928).

155*a*. Friedmann, *Bietr. Phys. Path.*, **3**, 38 (1902). *b*. Schöberl, *Z. physiol. Chem.*, **216**, 193 (1933); German pat., 604,016, *C.A.*, **29**, 818 (1935). *c*. Schmidt and Cerecedo, *Proc. Soc. Exptl. Biol. Med.*, **25**, 270 (1928). *d*. Mitchell, *J. Nutrition*, **4**, 95 (1931). *e*. Gordon, *J. Path. Bact.*, 29, 319 (1926). *f*. White and Fishman, *J. Biol. Chem.*, **116**, 457 (1936).

156. Strecker, *Ann.*, **91**, 97 (1854).

157*a*. Carl, *Ber.*, **12**, 1604 (1879); **14**, 63 (1881); Miyake, *J. Am. Chem. Soc.*, **37**, 2604 (1915).

158*a*. Kolbe, *Ann.*, **112**, 241 (1860); **122**, 33 (1862). *b*. Anschütz, *Ann.*, **415**, 97 (1918).

159. Kohler, *Am. Chem. J.*, **20**, 692 (1898); Marvel, Bailey, and Sparberg, *J. Am. Chem. Soc.*, **49**, 1833 (1927); Marvel and Bailey, *Org. Syntheses*, **10**, 98 (1930), John Wiley & Sons, New York.

160. Hausmann, German pat., 589,948, *C.A.*, **28**, 2370 (1934); French pat., 710,118, *C.A.*, **26**, 1000 (1932).

161*a*. Gabriel, *Ber.*, **21**, 2667 (1888). *b*. Reychler, *Bull. soc. chim. Belg.*, **32**, 247 (1923). *c*. Jacobi and Fikentscher, German pat., 572,204, *C.A.*, **27**, 2965 (1933). *d*. Cortese, *J. Am. Chem. Soc.*, **58**, 191 (1936).

162. Gabriel, *Ber.*, **22**, 1153, 1142 (1889).

163. Solkowski, *Ber.*, **49**, 1376 (1916).

164. Nicodemus and Schmidt, U. S. pat., 1,932,907, *C.A.*, **28**, 491 (1934); Groggins and Stirton, *Ind. Eng. Chem.*, **29**, 1353 (1937).

165. Nicodemus, Schmidt, Ossenbeck, and Tietze, U. S. pat., 1,999,614, *C.A.*, **29**, 4028 (1935).

166. I. G. Farbenind. A.-G., British pat., 406,380, *C.A.*, **28**, **4746** (1934).

167*a*. Dittrich, *J. prakt. Chem.*, **[2] 18**, 63 (1878). *b*. James, *J. Chem. Soc.*, **47**, **367** (1885); **49**, **486** (1886). *c*. Grotowsky and Mühl, German pat., 586,973, *C.A.*, **28**, 1359 (1934). *d*. Josephson, *Biochem. Z.*, **264**, 448 (1933). *e*. I. G. Farbenind. A.-G., British pat., **446**,337, *C.A.*, **30**, 6850 (1936); I. G. Farbenind. A.-G., French pat., 744,262, *C.A.*, **27**, 3949 (1933); French pat., 826,834, *C.A.*, **32**, 7926 (1938); Dickey and McNally, U. S. pat., 2,241,769, *C.A.*, **35**, 5133 (1941); Rumpf, *Compt. rend.*, **212**, 83 (1941).

168*a*. Brieger, *Zeit. physiol. Chem.*, **7**, 35 (1883). *b*. Teroaka, *ibid.*, **145**, 238 (1925). *c*. I. G. Farbenind. A.-G., French pat., 796,813, *C.A.*, **30**, 6011 (1936). *d*. British pat., 518,656, *C.A.*, **35**, 7587 (1941).

169. James, *J. prakt. Chem.*, [2] **34**, 350 (1886); *J. Chem. Soc.*, 49, 486 (1886).

170. Andrews and Schmidt, *J. Biol. Chem.*, **73**, 651 (1927); Josephson, *Acta Med. Scand.*, **68**, 284 (1928); *C.A.*, **22**, 2579 (1928).

171. Hedestrand, *Z. physik. Chem.*, **135**, 36 (1928); Devoto, *Atti accad. Lincei*, **15**, 471 (1932); *Gazz. chim. ital.*, **61**, 897 (1931).

172. Redtenbacher, *Ann.*, **65**, 37 (1848).

173*a*. Solkowsky, *Ber.*, **7**, 117 (1874). *b*. Engel, *Ber.*, **8**, 830 (1875).

174. Lang, *Ber.*, **9**, 853 (1876).

175. Bondi and Müller, *Zeit. physiol. Chem.*, **47**, 499 (1906).

176. Pellizzari and Matteucci, *Ann.*, **248**, 152 (1888).

177. Josephson, *Biochem. Z.*, **264**, 441 (1933).

178*a*. Guenther, Münz, and Haussmann, U. S. pat., 1,932,180, *C.A.*, **28**, 672 (1934). *b*. Lederer, *Angew. Chem.*, **47**, 119 (1934). *c*. Evans, *J. Soc. Dyers and Colourists*, **51**, 233 (1935); Duncan, *Ind. Eng. Chem.*, **26**, 25 (1934). *d*. I. G. Farbenind. A.-G., British pat., 461,614, *C.A.*, **31**, 5480 (1937); N. V. Chemische Fabriek "Servo" and Rosenbroek, British pat., 473,760, *C.A.*, **32**, 3055 (1938); Harst and Schild, U. S. pat., 2,213,984, *C.A.*, **35**, 829 (1941).

179*a*. Steindorff, Daimler, and Platz, German pat., 671,352, *C.A.*, **33**, 3494 (1939). *b*. I. G. Farbenind. A.-G., British pat., 499,879, *C.A.*, **33**, 5095 (1939). *c*. British pat., 501,004, *C.A.*, 33, 5948 (1939). *d*. Ulrich and Koerding, U. S. pat., 2,157,362, *C.A.*, **33**, 6483 (1939). *e*. Orthner, U. S. pat., 2,117,207, *C.A.*, **32**, 5112 (1938). *f*. I. G. Farbenind. A.-G., French pat., 802,142, *C.A.*, **31**, 1525 (1937). *g*. French pat., 47,851 (addition to 731,405), *CA.*, **32**, 4693 (1938); British pat., 481,357, *C.A.*, **32**, 6363 (1938). *h*. British pat., 446,912, *C.A.*, **30**, 6850 (1936). *i*. British pat., 500,032, *C.A.*, **33**, 5549 (1939).

180*a*. White, *J. Biol. Chem.*, **102**, 249 (1933); Abderhalden and Riesz, *Fermentforschung*, **12**, 180 (1930); *C.A.*, **25**, 492 (1931). *b*. Paal and Zitelmann, *Ber.*, **36**, 3343 (1903).

181*a*. Schmidt, *Proc. Soc. Explt. Biol. Med.*, **18**, 204 (1921). *b*. Neuberg, *Chem. Zentr.*, II, 1436 (1904).

182. I. G. Farbenind. A.-G., British pat., 427,943, *C.A.*, 29, 6772 (1935).

183. Gabriel and Hirsch, *Ber.*, 29, 2611 (1896).

184. Avenarius, *Ber.*, **24**, 266 (1891).

185. Gabriel, *Ber.*, **22**, 2987 (1889).

186. Gabriel and Hirsch, *Ber.*, 29, 2750 (1896); see *Ber.*, 50, 815 (1917).

187*a*. Gabriel and Colmann, *Ber.*, **39**, 2889 (1906). *b*. I. G. Farbenind. A.-G., French pat., 801,562, *C.A.*, **31**, 420 (1937); Doser, Schroter, and Bayer, German pat., 656,427, *C.A.*, **32**, 3519 (1938).

188. Bookman, *Ber.*, **28**, 3117 (1895).

189. Nicodemus and Schmidt, German pat., 612,536, *C.A.*, 29, 6251 (1935).

190. Gabriel and Lauer, *Ber.*, **23**, 92 (1890); Pinkus, *Ber.*, 26, 1079 (1893).

191. Kahan, *Ber.*, **30**, 1322 (1897).

192. I. G. Farbenind. A.-G., British pat., 382,922, *C.A.*, **27**, 4250 (1933); French pat., 738,842, *C.A.*, **27**, 1895 (1933); Nicodemus and Wulff, U. S. pat., 2,008,292, *C.A.*, 29, 5864 (1935).

193. Allardt and Schickh, German pat., 544,620, *C.A.*, **26**, 3519 (1932).

194. Bertagnini, *Ann.*, **85**, 179, 268 (1853); Kraut, *Ann.*, **258**, 105 (1890); Bunte, *Ann.*, **170**, 308 (1873); Chancel, *Ann.*, **151**, 302 (1869); Juslin, *Ber.*, **17**, 2505 (1884); Kahn, *Ber.*, **18**, 3365 (1885); Mendeleev, *Ann.*, **110**, 243 (1859); Lipp, *Ann.*, **205**, 3 (1880); Krafft, *Ber.*, **28**, 2361 (1890); Demijanow and Fortunatow, *Ber.*, **40**, 4398 (1907); Colman and Perkin, *J. Chem. Soc.*, **51**, 238 (1887); Freer and Perkin, *ibid.*, **53**, 214 (1888); Darzens, *Compt. rend.*, **144**, 1124 (1907); Fischer and Hoffa, *Ber.*, **31**, 1991 (1898); von Miller and Rohde, *Ber.*, **24**, 1359 (1891); **23**, 1075 (1890); Cannizzaro, *Ann.*, **119**, 254 (1861); Etard, *Ann. chim.*, [5] **22**, 248 (1881); Stoermer, *Ber.*, **39**, 2300 (1906); v. Richter and Schüchner, *Ber.*, **17**, 1933 (1884).

195*a*. Perkin, *J. Chem. Soc.*, **43**, 69 (1883); *Ber.*, **16**, 1029 (1883). *b*. Höchster Farbw., German pat., 121,975, *Chem. Zentr.*, II, 248 (1901).

196. Blaise and Guérin, *Bull. soc. chim.*, [3] **29**, 1202 (1903).

197. Tiffeneau and Dorlencourt, *Compt. rend.*, **143**, 1242 (1906); *Ann. chim. phys.*, [8] **16**, 248 (1909).

198. Kerp and Baur, *Chem. Zentr.*, II, 970 (1907).

199. Schäffer, *Ber.*, **4**, 367 (1871).

200. Kerp, *Chem. Zentr.*, II, 58 (1904); Kerp and Baur, *ibid.*, II, 970 (1907).

201. Bertagnini, *Ann.*, **85**, 183, 276 (1853); Jackson and White, *Ber.*, **11**, 1043 (1878); *Am. Chem. J.*, **3**, 31 (1881); Seelig, *Ann.*, **237**, 149 (1887); Erhart, German pat., 116,124, *Chem. Zentr.*, I, 70 (1901); Sachs and Kempf, *Ber.*, **35**, 1229 (1902); Hanzlik and Bianchi, *Ber.*, **32**, 1286 (1889); Etard, *Compt. rend.*, **87**, 990 (1878); *Ann. chim. phys.*, [5] **22**, 260 (1881); Cassella and Co., German pat., 290,209, *Frdl.*, **12**, 107.

202. Kobek, *Ber.*, **16**, 2097 (1883); Nordmann, *Ber.*, **17**, 2634 (1884).

203. Schramm, *Ber.*, **16**, 1583 (1883).

204. Limpricht, *Ann.*, **93**, 238 (1855); Städeler, *Ann.*, **111**, 307 (1859); Grimm, *Ann.*, **157**, 253 (1871); Popoff, *Ann.*, **145**, 289 (1868); Frankland and Duppa, *Ann.*, **138**, 212 (1866); **145**, 82 (1868); Béhal, *Ann. chim. phys.*, [6] **15**, 271 (1888); Petersen, *Ann.*, **118**, 77 (1861); Thoms, *Chem. Zentr.*, I, 524 (1901); Jourdan, *Ann.*, **200**, 106 (1880); Combes, *Ann. chim. phys.*, [6] **12**, 249 (1887); Kohler, *Am. Chem. J.*, **38**, 527 (1907); Radziszewski, *Ber.*, **3**, 198 (1870); Ehrlich, *Ann.*, **187**, 15 (1877); Errera, *Gazz. chim. ital.*, **21**, I, 100 (1891); Lipp and Scheller, *Ber.*, **42**, 1964 (1909).

205*a*. Kishner, *J. Russ. Phys.-Chem. Soc.*, **39**, 923 (1907); *Chem. Zentr.*, I, 123 (1908). *b*. Fittig, *Ann.*, **110**, 22 (1859); Pinner, *Ber.*, **15**, 594 (1882). *c*. Hentzschel and Wislecenus, *Ann.*, **275**, 315 (1893). *d*. Petrenko-Kritschenko, *Ann.*, **341**, 164 (1905). *e*. Wislecenus and Mager, *Ann.*, **275**, 362 (1893). *f*. Markownikoff, *J. prakt. Chem.*, [2] **49**, 414 (1894). *g*. Atkinson and Yoshida, *J. Chem. Soc.*, **41**, 51 (1882); Brunel, *Compt. rend.*, **140**, 793 (1905); *Bull. soc. chim.*, [3] **33**, 569 (1905). *h*. Wallach, *Ann.*, **277**, 135 (1893). *i*. Knoevenagel, *Ann.*, **297**, 163 (1897). *j*. Zelinsky and Reformatsky, *Ber.*, **28**, 2944 (1895). *k*. Kotz and Michels, *Ann.*, **350**, 213 (1906); **348**, 96 (1906). *l*. Dieckmann, *Ann.*, **317**, 85 (1901). *m*. Knoevenagel and Fischer, *Ann.*, **297**, 185 (1897). *n*. Tiemann and Schmidt, *Ber.*, **30**, 28 (1897). *o*. Kerp and Müller, *Ann.*, **299**, 231 (1898). *p*. Semmler, *Ber.*, **25**, 3343 (1892). *q*. Leroux, *Compt. rend.*, **144**, 981 (1907). *r*. Baeyer, *Ber.*, **27**, 1920 (1894). *s*. Darzens and Rost, *Compt. rend.*, **152**, 609 (1911). The reaction of resorcinol, phloroglucinol, and naphthols with sodium bisulfite may proceed through the addition of the bisulfite to the keto forms of the phenols. See Bucherer and Schmidt, *J. prakt. Chem.*, **79**, 369 (1909); Bucherer, *Ber.*, **53B**, 1457 (1920); Fuchs, *Ber.*, **54B**, 245 (1921); Fuchs and Stix, *Ber.*, **55B**, 658 (1922).

206*a*. Van Romburgh, *Rec. trav. chim.*, **5**, 233 (1886). *b*. Perkin and Sinclair, *J. Chem. Soc.*, **61**, 47 (1892).

207. Popoff, *Ann.*, **161**, 296 (1872); Schmidt and Fieberg, *Ber.*, **6**, 498 (1873); Friend and Pounder, *J. Chem. Soc.*, 2245 (1928).

208. Wagner, *J. prakt. Chem.*, [2] 44, 280 (1891); Markownikoff, *Ber.*, **33**, 1906 (1900); Desgrez, *Ann. chim. phys.*, [7] **3**, 235 (1894); Béhal, *Bull. soc. chim.*, [2] **50**, 359 (1888); Popoff, *Ber.*, **5**, 501 (1872).

209. Limpricht, *Ann.*, 94, 246 (1855).

210. Kleber, *Chem. Zentr.*, I, 1108 (1904); Mathieu, *ibid.*, II, 480 (1904).

211. Ripper, *Monatsh.*, **21**, 1079 (1900).

212. Burgess, *Analyst*, **29**, 78 (1904).

213. Sadtler, *J. Am. Chem. Soc.*, **27**, 1321 (1906).

214. Wagner, *Ber.*, **62**, 2873 (1929).

215*a*. Stewart and Donnally, *J. Am. Chem. Soc.*, **54**, 2333, 3555, 3559 (1932). *b*. Tomoda, *J. Soc. Chem. Ind. (Japan)*, **30**, 747 (1927); *C.A.*, **22**, 1822 (1928).

216*a*. Müller, *Ber.*, **6**, 1031 (1873). *b*. Reinking, Dehnel, and Labhardt, *Ber.*, **38**, 1071 (1905).

217. Raschig and Prahl, *Ann.*, **448**, 265 (1926); *Ber.*, **59B**, 2025 (1926); **61B**, 179 (1928); Raschig, *Ber.*, **59B**, 859 (1926).

218. Glimm, "Inaug. Diss.," Freiburg, 1902.

219. Schroeter, *Ber.*, **69B**, 2341 (1926); Schroeter and Sulzbacher, *Ber.*, **61B**, 1616 (1928).

220. Backer and Mulder, *Rec. trav. chim.*, **52**, 454 (1933); *ibid.*, **53**, 1120 (1934).

221. Lauer and Langkammerer, *J. Am. Chem. Soc.*, **57**, 2360 (1935); see also Shriner and Land, *J. Org. Chem.*, 6, 888 (1941).

222. Stelling, *Cellulosechemie*, 9, 100 (1928).

223. Hoover, Hunten, and Sankey, *J. Phys. Chem.*, **34**, 1361 (1930); Rumpf, *Compt. rend.*, **197**, 686 (1933).

224*a*. Rothmund, *Monatsh.*, **26**, 1545 (1905); see also Besanez and Grimm, *Ann.*, **151**, 277 (1869). *b*. R. Bayer, *chem. Fabrik*, German pat., 464,010, *C.A.*, **22**, 4131 (1928).

225. Bucherer and Schwalbe, *Ber.*, **39**, 2818 (1906).

226. Freundler and Bunel, *Compt. rend.*, **132**, 1338 (1901).

227*a*. Raschig, *Schwefel and Stickstoff-studien*, 242 (1924); Badische Anilin- und Sodafabrik, German pat., 165,807, *Chem. Zentr.*, I, **422** (1906). *b*. Shearing and Smiles, *J. Chem. Soc.*, 1348 (1937).

228. Ledbury and Taylor, *J. Soc. Chem. Ind.*, **45**, 85T (1926).

229. Grove-Palmer, *Pharm. J.*, **123**, 370 (1929); Lumière-Frères and Seyewetz, *Bull. soc. chim.*, [3] **15**, 1164 (1903); Bayer and Co., German pat., 145,398, *Chem. Zentr.*, II, 1043 (1903).

230. Dyke and King, *J. Chem. Soc.*, 1003 (1933).

231. Bucherer, German pat., 141,509, *Chem. Zentr.*, I, 1244 (1903); Knoevenagel and Lange, *Ber.*, **37**, 4060 (1904).

232. Schuster, *J. pharm. chim.*, **23**, 142 (1936).

233. Rost and Franz, *Chem. Zentr.*, II, 142 (1904).

234. Gastaldi and Braunizer, *Gazz. chim. ital.*, **52**, I, 307 (1922).
235. Magnus, *Pogg. Ann.*, **27**, 367 (1833); *Ann.*, **6**, 163 (1833).
236. Müller, *Ber.*, **6**, 1031 (1873).
237. Meves, *Ann.*, **143**, 196 (1867).
238. Liebig, *Ann.*, **12**, 27 (1834); **13**, 33 (1835).
239. Hübner, *Ann.*, **223**, 198 (1884).
240*a*. Regnault, *Ann. chim. phys.*, **45**, 98 (1838). *b*. *Ann.*, **27**, 11, 71 (1838); **25**, 32 (1838). *c*. Michael and Weiner, *J. Am. Chem. Soc.*, **58**, 294 (1936). *d*. See also Adams, Eatough, and Marvel, U. S. pat., 2,036,249, *C.A.*, **30**, 3442 (1936).
241. Magnus, *Pogg. Ann.*, **47**, 509 (1839).
242. Daimler and Platz, French pat., 716,914, *C.A.*, **26**, 2751 (1932); U. S. pat., 1,913,794, *C.A.*, **27**, 4248 (1933).
243. Claësson, *J. prakt. Chem.*, [2] **19**, 253 (1879).
244. Collmann, *Ann.*, **148**, 107 (1868).
245. Webel, German pat., 569,148, *C.A.*, **27**, 2457 (1933).
246. Erlenmeyer, *Chem. Zentr.*, 423 (1868).
247. Carl, *Ber.*, **14**, 63 (1881).
248. Seyberth, *Ber.*, **7**, 391 (1874); Carl, *Ber.*, **12**, 1604 (1879); **14**, 63 (1881).
249*a*. Backer, *Rec. trav. chim.*, **54**, 205 (1935). *b*. Bruson and Eastes, U. S. pat., 2,160,196, *C.A.*, **33**, 7434 (1939).
250*a*. Kolbe, *Ann.*, **122**, 38 (1862). *b*. Anschütz, *Ann.*, **415**, 97 (1918).
251. E. I. du Pont de Nemours and Co., British pat., 444,639, *C.A.*, **30**, 5597 (1936).
252*a*. Daimler and Platz, German pat., 652,410, *C.A.*, **32**, 1814 (1938). *b*. I. G. Farbenind. A.-G., French pat., 820,514, *C.A.*, **32**, 3055 (1938). *c*. British pat., 452,577, *C.A.*, **31**, 1121 (1937). *d*. Henkel et Cie G.m.b.H., French pat., 763,743, *C.A.*, **28**, 5697 (1934).
253*a*. Baldwin and Hailwood, U. S. pat., 2,062,957, *C.A.*, **31**, 784 (1937). *b*. I. G. Farbenind. A.-G., British pat., 452,866, *C.A.*, **31**, 1121 (1937). *c*. Bruson, U. S. pat., 2,115,192, *C.A.*, **32**, 4694 (1938); U. S. pat., 2,098,203, *C.A.*, **32**, 1278 (1933). *d*. Steindorff, Daimler, and Platz, German pat., 649,993, *C.A.*, **31**, 8544 (1937). *e*. Bruson, U. S. pat., 2,148,432, *C.A.*, **33**, 3927 (1939). *f*. Henke and Prahl, U. S. pat., 2,001,275, *C.A.*, **29**, 4375 (1935); see also Waldmann and Chwala, *C.A.*, **29**, 5546 (1935); German pat., 677,600, *C.A.*, **33**, 9327 (1939). *g*. Bruson and Eastes, U. S. pat., 2,132,675, *C.A.*, **33**, 400 (1939); British pat., 506,677, *C.A.*, **33**, 9493 (1939); van Antwerpen, *Ind. Eng. Chem.*, **31**, 64 (1939).
254. Salkowski, *Ber.*, **49**, 1376 (1916).
255. Kohler, *Am. Chem. J.*, **21**, 353 (1899).
256*a*. Garzins, *Jahresbericht*, 1327 (1889). *b*. Böhme, *Fettchemie-Gesellschaft* m.b.H., German pat., 687,462, *C.A.*, **35**, 4522 (1941). *c*. Cromwell and Merley, U. S. pat., 2,220,678, *C.A.*, **35**, 1412 (1941).
257. Suter, U. S. pat., 2,135,358, *C.A.*, **33**, 1064 (1939); see also Guenther and Haussmann, U. S. pat., 2,094,451, *C.A.*, **31**, 8755 (1937); Gohr, U. S. pat., 2,115,847, *C.A.*, **32**, 4694 (1938); Fulton and Vesterdaal, U. S. pat., 2,115,807, *C.A.*, **32**, 4694 (1938); I. G. Farbenind. A.-G., French pat., 847,549 *C.A.*, **35**, 5600 (1941).
258. Müller, *Ber.*, **6**, 1442 (1873); Rosenthal, *Ann.*, **233**, 33 (1886).
259. Marckwald and Frahne, *Ber.*, **31**, 1863 (1898).

260*a*. Nilsson, *Svensk Kem. Tid.*, **52**, 324 (1940); *C.A.*, **35**, 6236 (1940). *b*. Schrauth, U. S. pat., 2,066,542, *C.A.*, **31**, 1122 (1937).

261. I. G. Farbenind. A.-G., German pat., 657,404, *C.A.*, **32**, 4252 (1938).

262*a*. Friese, *Ber.*, **64B**, 2103 (1931). *b*. Baldeschwieler and Cassar, *J. Am. Chem. Soc.*, **51**, 2969 (1929). *c*. Shriner, Rendleman, and Berger, *J. Org. Chem.*, **4**, 103 (1939). *d*. Lipp and Holl, *Ber.*, **62B**, 499 (1929). *e*. Asahina, Sano, and Mayekawa, *Ber.*, **71B**, 312 (1938). *f*. Asahina and Yamaguchi, *Ber.*, **71B**, 318 (1938). *g*. McQueen, U. S. pat., 2,212,995, *C.A.*, **35**, 465 (1941).

263. Darmstädter, *Ann.*, **148**, 126 (1868).

264*a*. Wolff, German pat., 258,473 *Chem. Zentr.*, I, 1482 (1913). *b*. Sjöberg, *Svensk Kem. Tid.*, **50**, 250 (1938); *C.A.*, **33**, 2106 (1939). *c*. Colgate-Palmolive-Peet Co., British pat., 516,735, *C.A.*, **35**, 6357 (1941).

265. Schäuffelen, *Ann.*, **148**, 111 (1868); Pazschke, *J. prakt. Chem.*, [2] **1**, 86 (1870).

266*a*. Nicodemus and Schmidt, German pat., 651,733, *C.A.*, **32**, 686 (1938); French pat., 795,417, *C.A.*, **30**, 5595 (1936); Tsunoo, *Ber.*, **68B**, 1334 (1935). *b*. Waldmann and Chwala, U. S. pat., 2,118,995, *C.A.*, **32**, 5537 (1938). *c*. U. S. pat., 2,154,922, *C.A.*, **33**, 5550 (1939); addition to French pat., 796,917, *C.A.*, **33**, 5095 (1939). *d*. I. G. Farbenind. A.-G., British pat., 498,008, *C.A.*, **33**, 3926 (1939).

267. Dupont and Labaune, *C.A.*, **7**, 2188 (1913).

268. Bertsch, German pat., 652,433, *C.A.*, **32**, 1814 (1938); Price and Dombrow, U. S. pat., 2,241,421, *C.A.*, **35**, 5218 (1941).

269. Hueter, U. S. pat., 2,094,489, *C.A.*, **31**, 8754 (1937); Schrauth, German pat., 635,903, *C.A.*, **31**, 784 (1931); see also Steindorff, Balle, Heinke, and Horst, U. S. pats., 2,167,325 and 2,167,326, *C.A.*, **33**, 8858 (1939).

270*a*. Friedrich Steinfels, A.-G., British pats., 486,850 and 486,909, *C.A.*, **32**, 8631 (1938). *b*. Colgate-Palmolive-Peet Co., French pat., 837,370, *C.A.*, **33**, 7438 (1939). *c*. I. G. Farbenind. A.-G., British pat., 500,032, *C.A.*, **33**, 5549 (1939). *d*. Deutsche Hydrierwerke A.-G., French pat., 731,279, *C.A.*, **27**, 859 (1933).

271. Schroeter, *Ann.*, **418**, 253 (1919).

272. Engelhardt and Latschinoff, *Z. Chem.*, 271 (1868).

273. Monari, *Ber.*, **18**, 1347 (1885).

274. Lepouse, *Bull. soc. chim. Belg.*, **32**, 139 (1923); **34**, 133 (1925).

275. Nottbohm, *Ann.*, **412**, 53 (1916); see also J. R. Geigy A.-G., Swiss pats., 202,423 to 202,427, *C.A.*, **33**, 8858 (1939).

276. Haubner, *Monatsh.*, **12**, 543 (1891); Lieben and Zeisel, *ibid.*, **1**, 821 (1880).

277. Ludwig, *ibid.*, **9**, 664 (1888); Hayman, *ibid.*, **9**, 1055 (1888).

278. Tiemann, *Ber.*, **31**, 3309 (1898); **32**, 812 (1899); Kerp and Wöhler, *Chem. Zentr.*, II, 708 (1909).

279. Tiemann and Semmler, *Ber.*, **26**, 2710 (1893); Stiehl, *J. prakt. Chem.*, [2] **58**, 78 (1898); **59**, 498 (1899); Romeo, *Gazz. chim. ital.*, **48**, I, 45 (1918); Hibbert and Cannon, *J. Am. Chem. Soc.*, **46**, 119 (1924); Dodge, *Am. Perfumer*, **32**, No. 3, 67 (1936).

280. Bender, *Zeit. Chem.*, 162 (1870); Kriwaxin, *ibid.*, 267 (1871); Suter, Evans, and Kiefer, *J. Am. Chem. Soc.*, **60**, 538 (1938).

281. Parkes and Tinsley, *J. Chem. Soc.*, 1861 (1934).

282. Kao and Kung, *J. Chinese Chem. Soc.*, **3**, 213 (1935); *C.A.*, **29**, 7315 (1935).

283. Hofmann, *Ann.*, **201,** 81 (1880).

284*a*. Pinner, *Ber.*, **15,** 592 (1882). *b*. Harries, *Ber.*, **32,** 1326 (1899); *Ann.*, **330,** 188 (1904).

285. Labbe, *Bull. soc. chim.*, [3] **23,** 280 (1900).

286. Looft, *Ber.*, **27,** 1538 (1894); *Ann.*, **275,** 377 (1893).

287. Knoevenagel, *Ber.*, **37,** 4047 (1904).

288. Baeyer and Henrich, *Ber.*, **28,** 652 (1895).

289. Wallach and co-workers, *Nachr. Ges. Wiss. Göttingen,* 321 (1919); *C.A.*, **14,** 3652 (1920).

290. Treibs, *Ber.*, **70B,** 85 (1937).

291*a*. Guenther and Holsten, U. S. pat., 2,037,974, *C.A.*, **30,** 3911 (1936). *b*. Böhme Fettchemie-Ges. m.b.H., German pat., 665,237, *C.A.*, **33,** 1841 (1939).

292. Ralston, U. S. pat., 2,089,154, *C.A.*, **31,** 6769 (1937).

293. Windaus and Kuhr, *Ann.*, **532,** 52 (1937); Kuhr, *Ber.*, **72B,** 929 (1939); Windaus and Nielke, *Ann.*, **536,** 116 (1938).

294. Mazák and Šusko, *Roczniki Chem.*, **9,** 431 (1929); *C.A.*, **23,** 4187 (1929).

295. Reychler, *Bull. soc. chim.*, [3] **19,** 120 (1898); Poggi and Polverini, *Ann. chim. applicata,* **30,** 284 (1940); *C.A.*, **35,** 1395 (1941).

296. Armstrong and Lowry, *J. Chem. Soc.*, **81,** 1444 (1902); Bredt, Rochussem, and Heusch, *Ber.*, **35,** 1290 (1902); Wedekind, *Chem. Ztg.*, **36,** 658 (1913); Wedekind, Schenk, and Stresser, *Ber.*, **56,** 640 (1923); Grahm, *J. Chem. Soc.*, **101,** 746 (1912); Lipp and Lausberg, *Ann.*, **436,** 274 (1924); Burgess and Lowry, *J. Chem. Soc.*, **127,** 279 (1925); Loudon, *ibid.*, 823 (1933); Lipp and Knapp, *Ber.*, **73B,** 915 (1940).

297. Rewald, *Ber.*, **42,** 3136 (1909); Burgess and Gibson, *J. Soc. Chem. Ind.*, **44,** 496 (1925); Read and Grubb, *J. Chem. Soc.*, 188 (1931); Girault, *J. pharm. chim.*, **20,** 207 (1934).

298. Bredt, Houben, and Levy, *Ber.*, **35,** 1290 (1902).

299. Lipp and Holl, *Ber.*, **62,** 499 (1929).

300. Schreiber and Shriner, *J. Am. Chem. Soc.*, **57,** 1306, 1445, 1896 (1935).

301. Kipping and Pope, *J. Chem. Soc.*, **63,** 549 (1893); **67,** 357 (1895).

302*a*. Kipping and Pope, *ibid.*, **67,** 371 (1896). *b*. Kipping, *ibid.*, **79,** 372 (1901).

303. Pope and Read, *ibid.*, **97,** 992 (1910).

304. Hasselström, *Ann. Acad. Sci. Fennicae,* **30A,** No. 12 (1929).

305. Frèrejacque, *Compt. rend.*, **183,** 607 (1926).

306. Armstrong and Lowry, *J. Chem. Soc.*, **81,** 1451 (1902); Lowry and Magson, *ibid.*, **89,** 1047 (1906); Pope and Read, *ibid.*, **105,** 800 (1914); Richards and Lowry, *ibid.*, **127,** 1503 (1925).

307. Kipping, *J. Chem. Soc.*, **87,** 628 (1905); Pope and Peachey, *ibid.*, **73,** 893 (1898); Pope and Read, *ibid.*, **97,** 2199 (1910); see also Harvey and Lapworth, *ibid.*, **83,** 1107 (1903).

308. Delépine, Labro, and Lange, *Bull. soc. chim.*, [5] **1,** 1252 (1934).

309. Lapworth and Kipping, *J. Chem. Soc.*, **71,** 8 (1897).

310. Pope and Harvey, *ibid.*, **79,** 74 (1901).

311. Ingersoll and Babcock, *J. Am. Chem. Soc.*, **55,** 341 (1933).

312. Perkin and Robinson, *J. Chem. Soc.*, **99,** 788 (1911); Pope and Read, *ibid.*, **101,** 758 (1912).

313. Pope and Gibson, *ibid.*, **97,** 2207 (1910).

314. Burgess and Lowry, *ibid.*, **127,** 271 (1925).

315*a*. Strecker, *Ann.*, **148**, 90 (1868). *b*. See also Stillich, *J. prakt. Chem.*, [2] **73**, 538 (1906). *c*. Stillich, German pat., 185,183, *Chem. Zentr.*, II, 654 (1907). *d*. Hemilian, *Ann.*, **175**, 9 (1875). *e*. Bitto, *Ber.*, **30**, 1642 (1897). *f*. Rosenthal, *Ann.*, **233**, 15 (1886).

316. Backer and Van Mels, *Rec. trav. chim.*, **49**, 177 (1930).

317*a*. Backer and Van Mels, *ibid.*, **49**, 363 (1930). *b*. *Ibid.*, **49**, 457 (1930).

318. H. T. Böhme A.-G., French pat., 694,692, *C.A.*, **25**, 1842 (1931); Bertsch, U. S. pat., 1,910,459, *C.A.*, **27**, 3949 (1933).

319. Kalischer and Keller, U. S. pat., 1,851,102, *C.A.*, **26**, 2989 (1932).

320*a*. Brust, *Rec. trav. chim.*, **47**, 153 (1928). *b*. Bougault, *Ann. chim. phys.*, [8] **14**, 168 (1908).

321. Andreasch, *Monatsh.*, **43**, 485 (1923); **45**, 1 (1924); **46**, 23, 639 (1925); **48**, 145 (1927).

322. Melsens, *Ann.*, **52**, 276 (1844); Hemilian, *Ann.*, **176**, 1 (1875).

323*a*. Baumstark, *Ann.*, **140**, 81 (1866). *b*. Stillich, *J. prakt. Chem.*, [2] **73**, 539 (1906).

324. Peski, *Rec. trav. chim.*, **40**, 103 (1921).

325*a*. Franchimont, *Verslag. Akad. Wetensch. Amsterdam*, **16**, 368 (1881); *Compt. rend.*, **92**, 1055 (1881); *Rec. trav. chim.*, **7**, 26 (1888). *b*. Stillich, *Ber.*, **38**, 1245 (1905). *c*. Schneider and Seebach, *Ber.*, **54B**, 2298 (1921); Russell and Cameron, *J. Am. Chem. Soc.*, **60**, 1345 (1938).

326. N. V. Fabr. Van Chem. Prod., German pat., 275,846, *Frdl.*, **11**, 1191; German pat., 286,872, *Frdl.*, **12**, 77.

327. Kämmerer and Carius, *Ann.*, **131**, 165 (1864).

328. Backer and Dubsky, *Proc. Acad. Sci. Amsterdam*, **22**, 51 (1919); *C.A.*, **14**, 1662 (1920); *Rec. trav. chim.* **39**, 964 (1920).

329*a*. Hemilian, *Ann.*, **176**, 2 (1875). *b*. Buckton and Hofmann, *Ann.*, **100**, 152 (1857). *c*. Backer and DeBoer, *Proc. Acad. Sci. Amsterdam*, **26**, 79 (1923). *d*. *Rec. trav. chim.*, **43**, 297 (1924). *e*. Peski, *ibid.*, **40**, 736 (1921).

330*a*. Andreasch, *Monatsh.*, **8**, 413 (1887). *b*. Moll van Charante, *Rec. trav. chim.*, **24**, 71 (1905).

331. Backer and Toxopeus, *Rec. trav. chim.*, **45**, 890 (1926).

332. De Varda, *Gazz. chim. ital.*, **18**, 91 (1888).

333. Haymann, *Monatsh.*, **9**, 1064 (1888).

334*a*. Ludwig, *ibid.*, **9**, 666 (1888). *b*. Perkin, *J. Chem. Soc.*, **83**, 835 (1903). *c*. Horwitz, U. S. pat., 1,939,169, *C.A.*, **28**, 1479 (1934).

335. Krajčinović, *Ber.*, **59B**, 2117 (1926).

336. Krajčinović, *Ber.*, **62B**, 579 (1929).

337. Krajčinović, *Arch. Hem. Farm.*, **5**, 2 (1931); *C.A.*, **25**, 3955 (1931); *Ber.*, **63B**, 2276 (1930).

338. Russe, German pat., 662,182, *C.A.*, **32**, 7613 (1938).

339*a*. Oranienburger, Chem. Fabr. A.-G., German pat., 649,156, *C.A.*, **31**, 8755 (1937). *b*. Ulrich and Nüsslein, German pat., 663,808, *C.A.*, **33**, 280 (1939).

340. Andreasch, *Monatsh.*, **7**, 159, 171 (1886).

341. Backer, *Rec. trav. chim.*, **44**, 1056 (1925).

342. Backer and Mook, *Bull. soc. chim.*, **43**, 542 (1928).

343. Beilstein and Wiegand, *Ber.*, **18**, 483 (1885); Backer and Bloemen, *Rec. trav. chim.*, **45**, 100 (1926).

344. Valet, *Ann.*, **154**, 63 (1870); Mulder, *Rec. trav. chim.*, **50**, 719 (1931).

345. Backer and Beute, *Rec. trav. chim.*, **54**, 200, 523, 601 (1935).

346. Backer and Beute, *ibid.*, **54**, 551, 621 (1935).

347. Bougault and Mouchel-la-Fosse, *Compt. rend.*, **156**, 396 (1913).

348. Bartsch, *Ber.*, **36**, 1966 (1903).

349. Dey and Row, *J. Chem. Soc.*, **125**, 554 (1924).

350*a*. Rochleder, *J. prakt. Chem.*, **101**, 415 (1867). *b*. Liebermann and coworkers, *Ber.*, **13**, 1595 (1880); **14**, 477 (1881); **34**, 2608 (1901); **35**, 2919 (1902).

351. Dodge, *J. Am. Chem. Soc.*, **38**, 447 (1916).

352. Lasausse, *Bull. soc. chim.*, **13**, 893 (1913); *Compt. rend.*, **156**, 147 (1913); van der Zanden, *Rec. trav. chim.*, **54**, 289 (1935).

353*a*. Dreyfus, French pats., 636,586 and 637,335, *C.A.*, **23**, 536, 1297 (1929). *b*. Farb. und Gerbstoffe-Werke Carl Flesch, Jr., British pat., 282,626, *C.A.*, **22**, 3795 (1928); 284,206, *C.A.*, **22**, 4853 (1928); German pat., 564,759, *C.A.*, **27**, 1225 (1933); 617,347, *C.A.*, **30**, 3674 (1936). *c*. Voss, German pat., 678.678, *C.A.*, **33**, 9325 (1939). *d*. Imperial Chemical Industries, Ltd., French pat., 764,620, *C.A.*, **28**, 6010 (1934); I. G. Farbenind. A.-G., British pat., 346,945, *C.A.*, **26**, 2075 (1932). *e*. I. G. Farbenind. A.-G., German pat., 591,196, *C.A.*, 28, 2559 (1934). *f*. N. V. Chem. Fabriek "Servo" and Rozenbroek, British pat., 312,283, *C.A.*, **24**, 864 (1930). *g*. Dutch pat., 26,131, *C.A.*, **26**, 3397 (1932); 26,710, *C.A.*, **26**, 4494 (1932). *h*. Chem. und Seifenfabrik R. Baumheier A.-G., French pat., 721,041, *C.A.*, **25**, 4066 (1932). *i*. N. V. Chem. Fabriek "Servo" and Rozenbroek, French pat., 688,637, *C.A.*, **25**, 1112 (1931). *j*. Kern, German pat., 636,136, *C.A.*, **31**, 784 (1937). *k*. Chem. Fabriek Milch A.-G., British pat, 275,267, *C.A.*, **22**, 2284 (1928); 288,126, *C.A.*, **23**, 536 (1929). *l*. Lindner and Zickermann, German pat., 583,686, *C.A.*, **28**, 1212 (1934); 611,443, *C.A.*, **29**, 8381 (1935). *m*. I. G. Farbenind. A.-G., French pat., 645,819, *C.A.*, **23**, 2057 (1929). *n*. Orianenburger, Chem. Fabrik A.-G., French pat., 801,022, *C.A.*, **31**, 116 (1937). *o*. Russe and Zickermann, German pat., 663.984, *C.A.*, **33**, **278** (1939). *p*. I. G. Farbenind. A.-G., French pat, 816,667, *C.A.*, **32**, 2251 (1938). For many other references to the action of sulfonating agents on oils, see Chapter I.

354*a*. Bauer and Stockhausen, *J. prakt. Chem.*, [2] **130**, 35 (1931); Pomeranz, *Seifensieder-Ztg.*, 59, 79 (1932). *b*. Pomeranz, *ibid.*, **59**, 3 (1932); Bauer and Stockhausen, *ibid.*, 59, 34 (1932).

355. Haussmann, German pat., 550,243, *C.A.*, **26**, 4067 (1932); Lindner and Russe, German pat., 564,758, *C.A.*, **27**, 1009 (1933).

356. Haussmann, U. S. pat., 1,931,491, *C.A.*, **28**, 491 (1934).

357. Winokuchi and Iida, *J. Soc. Chem. Ind. Japan*, **38**, Suppl. binding **25** (1935); *C.A.*, **29**, 2767 (1935).

358. Carius, *Ann.*, **124**, **52** (1862).

359. Carl, *Ber.*, **14**, 64 (1881).

360. Preisler and Preisler, *J. Biol. Chem.*, **89**, 631 (1930).

361*a*. Andreasch, *Monatsh.*, **4**, 131 (1883). *b*. *Ibid.*, **7**, 162 (1886). *c*. *Ibid.*, **7**, 28 (1886).

362. Fichter, *Z. Elektrochem.*, **20**, 471 (1914).

363. Schneider and Seebach, *Ber.*, **54B**, 2285, 2298 (1921); Schneider and Kunau, *Ber.*, **54B**, **2302** (1921); Schneider and Kraft, *Ber.*, **55B**, 1892 (1922).

364. Gottesmann, *Ber.*, **66B**, 1168 (1933).

365. Backer and Dubsky, *Rec. trav. chim.*, **41**, 145 (1922).

366. Siemens, *Ber.*, 6, 659 (1873).

367. Manzelius, *Ber.*, **21**, 1550 (1888).

368. J. R. Geigy A.-G., Swiss pats., 160,079-160,081, *C.A.*, **28**, 670 (1934); Swiss pat., 162,732, *C.A.*, **28**, 2933 (1934); Swiss pats., 165,385 to 165,400, *C.A.*, **28**, 2934 (1934); Harris, U. S. pat., 2,166,141, *C.A.*, **33**, 8333 (1939); U. S. pats., 2,166,142 & 2,166,143, *C.A.*, **33**, 8333 (1939) cover the esters of higher sulfo-fatty acids; see also Harris and Cahn, U. S. pat., 2,251,932, *C.A.*, **35**, 7585 (1941); Harris, U. S. pat., 2,221,377, *C.A.*, **35**, 1549 (1941).

369. Hentrich and Keppler, U. S. pat., 1,931,540, *C.A.*, **28**, 670 (1934); German pat., 677,013, *C.A.*, **33**, 6998 (1939).

370*a*. Guenther, Holsten, and Saften, U. S. pat., 1,932,178, *C.A.*, **28**, 671 (1934). *b*. Epstein and Katzman, U. S. pats., 2,236,529 and 2,236,530, *C.A.*, **35**, 4521 (1941). *c*. Katzman, U. S. pat., 2,236,541, *C.A.*, **35**, 4521 (1941).

371. Böeseken, Klamer, and De Voogt, *Rec. trav. chim.*, **32**, 17 (1913).

372. Lepouse, *Bull. soc. chim. Belg.*, 32, 139 (1923); 34, 133 (1925).

373. Rathke, *Ann.*, **161**, 166 (1872).

374*a*. Porcher, *Bull. soc. chim.*, [3] **27**, 440 (1902). *b*. Backer and Burgers, *J. Chem. Soc.*, **127**, 233 (1925).

375. Pope and Read, *ibid.*, **93**, 796 (1908); Read and McMath, *ibid.*, 2192 (1926).

376. Backer, *Rec. trav. chim.*, **44**, 1056 (1925).

377 Backer and Mook, *Proc. Acad. Sci. Amsterdam*, **28**, 65 (1925); *C.A.*, **19**, 2637 (1925).

378. Backer and Mook, *Rec. trav. chim.*, **47**, 464 (1928).

379. Brust, *ibid.*, **47**, 153 (1928).

380. Franchimont and Backer, *ibid.*, **39**, 689 (1920).

381. Franchimont and Backer, *C.A.*, **9**, 1768 (1915).

382. Backer, *Rec. trav. chim.*, 40, 582 (1921).

383. Mulder, *ibid.*, **51**, 174 (1932).

384. Bigelow, Sigmon, and Wilcox, *J. Am. Chem. Soc.*, **57**, 2521 (1935).

385. Backer and Beute, *Rec. trav. chim.*, **54**, 523 (1935).

386. Preisler and Preisler, *J. Am. Chem. Soc.*, **54**, 2984 (1937).

387. Preisler and Preisler, *J. Biol. Chem.*, **95**, 181 (1932).

388. Andrews, *ibid.*, **97**, 657 (1932).

389. Andrews, *ibid.*, **102**, 263 (1933).

390. Ghosh and Kar, *J. Indian Chem. Soc.*, **11**, 485 (1934).

391. Schöberl, *Z. physiol. Chem.*, **216**, 193 (1933); German pat., 604,016, *C.A.*, **29**, 818 (1935).

392. Shinohara, *Am. J. Med. Sci.*, **182**, 880 (1931); *J. Biol. Chem.*, **96**, **285** (1932); Shinohara and Kilpatrick, *J. Am. Chem. Soc.*, **56**, 1466 (1934).

393. Toennies, *ibid.*, **56**, 2198 (1934).

394. Preisler and Preisler, *J. Phys. Chem.*, **38**, 1099 (1934).

395. Vickery and Leavenworth, *J. Biol. Chem.*, **86**, 129 (1930); Preisler and Preisler, *J. Phys. Chem.*, **38**, 1199 (1934); Lavine, *J. Biol. Chem.*, **117**, 309 (1937).

396. Simonsen, *ibid.*, **101**, 35 (1933).

397. Toennies and Lavine, *ibid.*, **105**, 107 (1934).

398. Lissizin, *Z. physiol. Chem.*, **173**, 309 (1928).

399. Gortner and Hoffman, *J. Biol. Chem.*, **72**, 433 (1927).

400. Andrews and Schmidt, *ibid.*, **73**, 651 (1927).

401. Clark and Inouye, *ibid.*, **94**, 541 (1931).

402. Stadie and O'Brien, *ibid.*, **112**, **723** (1936).

403. Andrews, Johnston, and Andrews, *Am. J. Physiol.*, **115**, 118 (1936); Andrews and Johnston, *J. Biol. Chem.*, **101**, **635** (1933).

404. Medes, *Biochem. J.*, **31**, **1330** (1937).

405. White, Lewis, and White, *J. Biol. Chem.*, **117**, 663 (1937).

406. White, *ibid.*, 102, 249 (1933).

407. Backer and Toxopeus, *Rec. trav. chim.*, **45**, 890 (1926).

408. Levene and Mikeska, *J. Biol. Chem.*, **70**, 365 (1926).

409. Nottbohm, *Ann.*, 412, 49 (1916).

410. Behrend and Koolman, *Ann.*, **394**, 228 (1913).

411. Naik and Amin, *J. Indian Chem. Soc.*, **5**, 579 (1928).

412. Naik and Shah, *ibid.*, **7**, 111 (1930).

413. I. G. Farbenind. A.-G., French pat., 834,205, *C.A.*, **33**, 3927 (1939); British pat., 499,130, *C.A.*, **33**, 4702 (1939).

414. Fehling, *Ann.*, **38**, 285 (1841); van der Zanden, *Rec. trav. chim.*, 46, 473 (1927).

415. Carius, *Ann.*, 129, 9 (1864).

416. Andreasch, *Monatsh.*, **16**, **794** (1895).

417. Backer and van der Zanden, *Rec. trav. chim.*, **46**, 473 (1927).

418. Credner, *Z. Chem.*, 77 (1870); Hägglund and Ringbom, *Z. anorg. allgem. Chem.*, **150**, 231 (1926).

419*a*. van der Zanden, *Rec. trav. chim.*, **45**, 424 (1926). *b*. Messel, *Ann.*, **157**, 15 (1871).

420. Jaeger, U. S. pat., 2,028,091, *C.A.*, **30**, 1466 (1936); Ross, *Am. Dyestuff Reptr.*, 26, 825 (1937); Caryl and Ericks, *Ind. Eng. Chem.*, **31**, 44 (1939); Caryl, *ibid.*, **33**, 731 (1941); Jaeger, U. S. pat., 2,252,401, *C.A.*, **35**, 7585 (1941); Epstein and Katzman, U. S. pats., 2,236,528 and 2,236,529, *C.A.*, **35**, 4521 (1941).

421. Tanatar, *J. Russ. Phys.-Chem. Soc.*, **43**, 1742 (1911); *C.A.*, **6**, 1279 (1912); Tanatar and Volyanskii, *J. Russ. Phys.-Chem. Soc.*, **44**, 1320 (1912); *C.A.*, **7**, 984 (1913).

422. Backer and van der Zanden, *Rec. trav. chim.*, **47**, 776 (1928); 49, 735 (1930).

423. Backer and Buining, *ibid.*, 46, 847 (1927); **47**, 111, 1000 (1928).

424. Andreasch, *Monatsh.*, **18**, 66 (1897).

425. Wieland, *Ann.*, **157**, 34 (1871).

426. Kachler, *Ann.*, **169**, 181 (1873); Königs and Hoerlin, *Ber.*, 26, 2046 (1893).

427. van der Zanden, *Rec. trav. chim.*, **53**, 477 (1934).

428. van der Zanden, *ibid.*, **53**, 591 (1934).

429. Backer and van der Zanden, *ibid.*, 49, 735 (1930).

430. van der Zanden, *ibid.*, **54**, 289 (1935).

431. van der Zanden, *ibid.*, **54**, 561 (1935).

432. Liebig, *Ann.*, **13**, 35 (1835); Wetherill, *Ann.*, **66**, 122 (1848); Strecker, *Ann.*, **100**, 199 (1856).

433. Hübner, *Ann.*, **223**, 208 (1884).

434*a*. Buckton and Hofmann, *Ann.*, **100**, 133 (1856). *b*. Kipping, *J. Chem. Soc.*, 222 (1931).

435. Baumstark, *Ann.*, **140**, 82 (1866).

436. Strecker, *Ann.*, **118**, **290** (1861).

437*a*. Schroeter, *Ber.*, **31**, 2189 (1898). *b*. *Ann.*, **303**, 114 (1898). *c*. **418**, 183 (1919). *d*. Muthmann, *Ber.*, **31**, 1880 (1898). *e*. Schroeter, German pat., 632,610, *C.A.*, **31**, 117 (1937).

438. Delépine, *Compt. rend.*, **133**, 876 (1901); *Bull. soc. chim.*, [3] **27**, 7 (1902).

439. Rathke, *Ann.*, **161**, 152 (1872).

440. Monari, *Ber.*, **18**, 1349 (1885).

441. Pechmann and Manck, *Ber.*, **28**, 2379 (1895).

442. Husemann, *Ann.*, **126**, 293 (1863).

443. Backer, *Rec. trav. chim.*, **48**, 571 (1929).

444. Backer, *ibid.*, **48**, 949 (1929).

445. Ostwald, *Z. physik. Chem.*, **1**, 107 (1887).

446. Backer and Terpstra, *Rec. trav. chim.*, **48**, 1175 (1929); **49**, 559 (1930).

447. Schroeter and Herzberg, *Ber.*, **38**, 3390 (1905).

448. Flesch-Werke A.-G., für Gerbstoff-fabr. u. Chem. Prod., British pat., 411,773, *C.A.*, **28**, 6726 (1934).

449. Flesch-Werke A.-G. für Gerbstoff-fabr. u. chem. Prod., British pat., 406,889, *C.A.*, **28**, 4930 (1934).

450*a*. Schroeter and Sondag, *Ber.*, **41**, 1921 (1908). *b*. Schroeter, *Ann.*, **418**, 161 (1919). *c*. Bauer and Jenkins, *J. Am. Pharm. Assoc.*, **26**, 485 (1937).

451. Schroeter and Herzberg, *Ber.*, **38**, 3391 (1905).

452. Backer and Stedehouder, *Rec. trav. chim.*, **50**, 931 (1931).

453. Farb. vorm. Bayer and Co., German pat., 171,935, *Chem. Zentr.*, II, 572 (1906).

454. Kohler, *Am. Chem. J.*, **19**, 731 (1897).

455. Kohler, *Am. Chem. J.*, **20**, 680 (1898).

456. Klaver, *Rec. trav. chim.*, **54**, 208 (1935).

457. Backer, *ibid.*, **49**, 729 (1930).

458. Backer, *ibid.*, **49**, 1054 (1930).

459. Backer, *ibid.*, **48**, 616 (1929).

460*a*. Etard, *Compt. rend.*, **88**, 649 (1879). *b*. v. Pechmann and Manck, *Ber.*, **28**, 2374 (1895). *c*. Backer and Mulder, *Rec. trav. chim.*, **51**, 769 (1932). *d*. Delépine and Demars, *Bull. Sci. Pharmacol.*, **29**, 14 (1922).

461. Pechmann, *Ber.*, **29**, 2161 (1896); German pat., 79,885, *Ber.*, **28**, R 522 (1895).

462*a*. Fantl and Fisch, *J. prakt. Chem.*, **124**, 159 (1930). *b*. Delanoe, *Compt. rend.*, **138**, 424 (1904).

463*a*. Rathke, *Ber.*, **3**, 858 (1870). *b*. Albrecht, *Ann.*, **161**, 129 (1872).

464. Backer, *Rec. trav. chim.*, **50**, 268 (1931); **51**, 988 (1932).

465. Backer, *ibid.*, **51**, 775, 981 (1932).

466. Chem. Fabr. von Heyden, German pat., 212,070, *Chem. Zentr.*, II, 766 (1909).

467. Flesch, Flesch, and Abelmann, British pat., 425,942, *C.A.*, **29**, 5546 (1935).

468. Flesch, French pat., 763,426, *C.A.*, **28**, 5698 (1934).

469. Guareschi, *Ber.*, **12**, 682 (1879); *Ann.*, **222**, 302 (1884).

470. Manzelius, *Ber.*, **21**, 1551 (1888).

471. Autenrieth and Bernheim, *Ber.*, **37**, 3808 (1904).

472. Delépine, *Compt. rend.*, **133**, 877 (1901); *Bull. soc. chim.*, [3] **27**, 10 (1902).

473. Werner, *Jahresbericht*, 425 (1862).

474. Buff, *Ann.*, **100**, 232 (1856).

475. Miolati, *Ann.*, **262**, 66 (1891); Husemann, *Ann.*, **126**, **272** (1863); Kucera, *Monatsh.*, **85**, 149 (1914).

476. Buckton and Hofmann, *J. Chem. Soc.*, 9, 250 (1857).

477. Meyer, *Ann.*, **171**, 53 (1874).

478. Fichter, *Z. Elektrochem.*, 20, 473 (1914); Fichter and Lichtenhahn, *Ber.*, 48, 1950 (1918).

479*a*. James, *J. Chem. Soc.*, **43**, 44 (1883). *b*. Autenrieth and Rudolph, *Ber.*, **34**, 3473 (1901).

480. For example see Bleicher, *Z. Kryst. Mineral.*, **51**, 502 (1913).

481. Berthelot, *Compt. rend.*, **69**, 563 (1869).

482. Königs, *Ber.*, **7**, 1163 (1874).

483*a*. Autenrieth and Koburger, *Ber.*, **36**, 3626 (1903). *b*. Clutterbuck and Cohen, *J. Chem. Soc.*, **121**, 120 (1922).

484. Autenrieth and Bernheim, *Ber.*, **37**, 3806 (1904).

485. Hagelberg, *Ber.*, **23**, 1089 (1890).

486. Stone, *J. Am. Chem. Soc.*, **58**, 488 (1936); **62**, 571, 572 (1940).

487. Autenrieth and Bölli, *Ber.*, **58B**, 2144 (1925).

488. Theilkuhl, *Ann.*, **147**, 134 (1868).

489. Backer and Klaassens, *Rec. trav. chim.*, **49**, 1107 (1930).

490. Bagnall, *J. Chem. Soc.*, **75**, 278 (1899).

491. Rathke, *Ann.*, **167**, 219 (1873).

492. Pechmann and Manck, *Ber.*, **28**, 2382 (1895).

493. Backer and Klaassens, *Rec. trav. chim.*, **49**, 1045 (1930).

494. Backer, *ibid.*, **51**, 374 (1932).

495. Backer and Terpstra, *ibid.*, 50, 1069 (1931).

496*a*. Kohler, *Am. Chem. J.*, **19**, 728 (1897). *b*. **20**, 680 (1898). *c*. **21**, 349 (1899).

497. Nicodemus and Schmidt, German pat., 678,730, *C.A.*, **33**, 9326 (1939).

498. Riesz, *Ber.*, **64B**, 1895 (1931).

499. Neugebauer and Mengel, German pat., 677,843, *C.A.*, **33**, 9325 (1939).

500*a*. Rad, *Ann.*, **161**, 218 (1872). *b*. Simo and O'Connor, U. S. pat., 2,243,331, *C.A.*, **35**, 5599 (1941).

501. Rosenthal, *Ann.*, **233**, 38 (1886).

502*a*. Clutterbuck and Cohen, *J. Chem. Soc.*, **121**, 120 (1922). *b*. Simo, O'Connor, and Parsons, U. S. pat., 2,243,332, *C.A.*, **35**, 5598 (1941).

503. Malkemus, Ph.D. thesis, Northwestern University, 1939; Suter and Malkemus, *J. Am. Chem. Soc.*, **63**, 978 (1941); Suter, Malkemus, and Archer, *ibid.*, **63**, 1594 (1941).

504. Haussmann, U. S. pat., 1,931,491, *C.A.*, 28, 491 (1934); British pat., 306,052, *C.A.*, **23**, 4951 (1929); French pat., 654,080, *C.A.*, **23**, 3716 (1929); Werntz, U. S. pat., 2,240,920, *C.A.*, **35**, 5126 (1941); Nawiasky and Sprenger, U. S. pat., 2,219,748, *C.A.*, **35**, 1067 (1941).

505. Downing and Clarkson, U. S. pats., 2,061,617, 2,061,618, 2,061,619 and 2,061,620, *C.A.*, **31**, 783 (1937).

506. I. G. Farbenind. A.-G., British pat., 303,917, *C.A.*, **23**, 4581 (1929); Gunther and Hetzer, German pat., 677,463, *C.A.*, **33**, 6996 (1939).

507. Fasce and Owen, Canadian pat., 380,241, *C.A.*, **33**, 3816 (1939).

508. Hintermaier, U. S. pat., 2,084,253, *C.A.*, **31**, 5481 (1937).

509. Windaus and Kuhr, *Ann.*, **532**, 52 (1937).

510. Lasarenko, *Ber.*, **7**, 125 (1874).

511. I. G. Farbenind. A.-G., German pat., 582,565, *C.A.*, **28**, 686 (1934); 585,623, *C.A.*, **28**, 1572 (1934).
512. Quilico, *Atti accad. Lincei,* [6] **7,** 141 (1928); Quilico and Fleischner, *ibid.*, [6] **7,** 1050 (1928); *C.A.*, **23,** 1628 (1929).
513. Nicodemus and Schmidt, German pat., 612,536, *C.A.*, **29,** 6251 (1935).
514. Pope and Kipping, *J. Chem. Soc.,* 2591 (1930).
515. Krafft and Heizmann, *Ber.,* **33,** 3588 (1900).

CHAPTER III

THE PREPARATION OF AROMATIC SULFONIC ACIDS

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The literature of the aromatic sulfonic acids is voluminous. This may be attributed to the ease with which these compounds are prepared and their commercial utility, particularly in the synthesis of drugs and dyestuffs. It is the purpose of this chapter to examine in some detail the methods that are available for obtaining sulfonic acids in which the sulfo group is attached to an aromatic ring of either the homocyclic or heterocyclic type and to indicate what compounds have been prepared by each method.

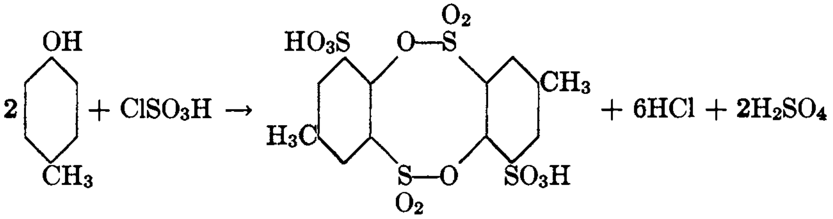
A. SULFONATION REACTIONS*

Sulfonic acids are obtained most readily through the direct replacement of hydrogen by the sulfo group. This method, which is of considerable technical importance, involves the utilization of any one of a number of sulfonating agents; in addition to sulfuric acid of various concentrations and in the presence of a variety of catalysts, these reagents include fluorosulfonic acid, chlorosulfonic acid, salts of chlorosulfonic acid, chlorosulfonic anhydride (pyrosulfuryl chloride), sulfamic acid (aminosulfonic acid), sulfur trioxide or its addition product with a slightly basic substance such as pyridine or dioxane, and acid salts of sulfuric acid. The reagent chosen in a particular case depends upon the compound to be sulfonated and the number of sulfo groups to be introduced. If fluoro- or chlorosulfonic acid is employed the sulfonic acid first formed may be converted into a sulfonyl halide by the presence of an excess of the sulfonating agent.

$$C_6H_6 + ClSO_3H \rightarrow C_6H_5SO_3H + HCl$$

$$C_6H_5SO_3H + ClSO_3H \rightarrow C_6H_5SO_2Cl + H_2SO_4$$

Sulfone formation occurs to a varying extent as a side reaction. It is especially noticeable when the compound sulfonated is present in excess and a very active reagent such as sulfur trioxide or chlorosulfonic acid is employed. In addition, a number of substituted phenols are converted by vigorous sulfonation into sulfonylides, bimolecular compounds containing two ester linkages.



The presence of certain groups in the aromatic ring seriously limits the use of sulfonating agents, particularly at elevated temperatures, because of the side reactions that may be induced. Bromine and more frequently iodine compounds undergo rearrangement or disproportionation under some conditions. Certain polyalkylated benzenes are characterized by similar changes, a phenomenon known as the Jacobsen reaction. Nitrobenzene cannot be heated above 170° with sulfuric acid without violent decomposition occurring, and *p*-nitrophenol must be sulfonated at 0° to obtain a satisfactory yield of sulfonic acid.

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* **References for this section on p. 324.**

The directive influence of certain substituents present in the aromatic ring is different in sulfonations than it is for other substitution reactions. For example, the halobenzenes sulfonate 100% *para* to the halogen while nitration occurs both *ortho* and *para*. There have been published recently[1] extensive data pertaining to a comparison of the directive influence of various groups in nitration and sulfonation reactions. In many instances, a change in the temperature at which a sulfonation is performed alters the position taken by the entering group or produces a rearrangement of the primary reaction product into a more stable isomer. This is particularly true in the naphthalene series. Mercuric sulfate likewise has a pronounced effect in determining the structure of a sulfonation product. This is most noticeable in the sulfonation of compounds that have keto or carboxyl groups attached to the aromatic ring. The effect is probably caused by mercuration followed by cleavage of the mercuri linkage with sulfur trioxide.

$$\mathrm{ArHgSO_4H + SO_3 \rightarrow ArSO_3HgSO_4H}$$

A number of interesting discussions have appeared[2] that deal with the theory of sulfonation reactions in which sulfuric acid is employed. Such a sulfonation is a reversible process that is complicated by the

$$\mathrm{ArH + H_2SO_4 \rightleftharpoons ArSO_3H + H_2O}$$

combination of the water formed in the reaction with sulfuric acid or the sulfonic acid to yield a hydrate. The concentration of a given aromatic compound in the sulfonation mixture not only varies with temperature but also with the quantity of water and of sulfonic acid present. Since aromatic hydrocarbons and their halogen derivatives are not appreciably soluble in sulfuric acid, other things being equal they sulfonate more slowly than the readily soluble oxygen, nitrogen, and sulfur derivatives. Since there is no evidence that sulfuric acid ever adds to an olefin bond as hydroxyl and sulfonate groups, the old hypothesis that sulfonation proceeds through such an intermediate addition product has no experimental foundation. Where the reagent is sulfur trioxide or chlorosulfonic acid the intermediate formation of an addition product is more plausible.

The extent to which a sulfonation reaction has proceeded may be determined quantitatively by a number of methods.[3] The most general one depends upon the drop in acidity of the reaction mixture, since for every mole of a sulfonic acid produced the acidity is decreased by one equivalent. If a mixture of mono- and disulfonic acids is formed the percentage of each can be determined by analyzing a sample of the dried calcium or barium sulfonates for the metal content. For particular acids a variety of estimation methods has been developed. These include conversion of the sulfonic acid or sulfonate to the sulfonyl chloride, precipitation of the sulfonic acid as an arylamine salt, and coupling of a sulfonated naphthol with a diazonium compound.

With the exception of aminosulfonic acids and certain others of high molecular weight it is more convenient to isolate salts of the acids than the acids because the acids are for the most part hygroscopic liquids or solids that are difficult to purify. In many instances the acids have not been prepared and in the following pages when reference is made to a sulfonic acid it is probable that it is known only in the form of its salts. The properties of the sulfonic acids and their chlorides and amides are given in tabular form later.

With comparatively few exceptions the alkali metal sulfonates are readily soluble in water; the solubility is less where high-molecular-weight aryl groups are present and increases as the number of sulfo groups in the molecule is increased. They are generally obtainable by salting them out of solution with excess of a readily soluble alkali salt. A more universally applicable procedure is to neutralize a sulfonation mixture with lime or other basic substance that will precipitate the sulfate ions, filter, and treat the filtrate with an alkali carbonate or sulfate. The filtrate from this operation is then evaporated until crystallization of the sulfonate occurs. The alkali earth and lead salts of the sulfonic acids, while generally soluble in water, frequently show marked variations for isomeric compounds so that it is possible to separate many sulfonation mixtures into their components by fractional crystallization of the calcium, barium, or lead salts of the sulfonic acids.

In the following discussion of sulfonation reactions, "sulfuric acid" refers to the concentrated acid of commerce. The expression "sulfuric acid monohydrate" which occurs frequently in the older literature and which refers to 100% sulfuric acid is not used here because it is ambiguous. The commonly employed term "oleum" is used in place of the longer "fuming sulfuric acid"; the percentage of sulfur trioxide present is mentioned where this was stated in the original. Where it was not stated the value is probably in the neighborhood of 20%.

Sulfonation of Benzene and Its Monoalkyl Derivatives

Monosulfonation of Benzene. The reaction of benzene with sulfuric acid is slow at room temperature.[4] When benzene is refluxed with an equal volume of sulfuric acid, equilibrium is reached in 20 to 30 hours,[5a] some 80% of the benzene reacting. By the use of a somewhat larger amount of acid the sulfonation may be made complete,[5b,c,d] this occurring rapidly when a large excess [5e] is employed. At temperatures from about 100° to 200° the reaction attains equilibrium [6,7,8] when the concentration of the sulfuric acid drops to 73–74%.

$$C_6H_6 + H_2SO_4 \rightleftharpoons C_6H_5SO_3H + H_2O$$

This corresponds to a hydrate of $H_2SO_4 \cdot 1.5H_2O$. The lower limit of concentration of the acid, calculated as sulfur trioxide, at which sulfonation can occur under a given set of conditions has been defined as the π of sulfonation.[8,9,10]

By passing benzene vapor through sulfuric acid kept at 100° or higher, usually 150–180°, practically all the acid is utilized in the sulfonation reaction; [6,7,8,11] under these conditions the water is removed by the excess of benzene vapor as soon as the concentration of the acid drops below about 90%. If the reaction is carried to completion the phenyl sulfone formed may amount to 4–5% while stopping the reaction, when 4–4.5% of the sulfuric acid remains, limits the sulfone to about 1%. Like sulfonation, sulfone formation is a reversible reaction,

$$C_6H_5SO_3H + C_6H_6 \xrightarrow{H_2SO_4} (C_6H_5)_2SO_2 + H_2O$$

for Gericke [12] and Kekulé [13] noted that phenyl sulfone is converted into benzenesulfonic acid by sulfuric acid. On a plant scale, 80% or more of the sulfuric acid is converted into benzenesulfonic acid. This method of sulfonation is applicable to other readily volatile hydrocarbons such as toluene or the xylenes. For high-boiling substances an auxiliary [14] liquid unaffected by sulfuric acid, such as carbon tetrachloride, or an inert gas, such as carbon dioxide, may be used to remove the water formed. When the reacting substance is not volatile, as in the sulfonation of benzenesulfonic acid, the reaction may be carried out under reduced pressure [15] to remove the water by distillation. Another method for maintaining the concentration of sulfuric acid high enough for sulfonation to proceed is to pass sulfur trioxide into the reaction mixture; this combines with the water as fast as it is produced.[16a] Sulfonation is also facilitated by the presence of boron trifluoride [16c] or hydrogen fluoride.[16d] The benzenesulfonic acid may be removed from a sulfonation mixture by continuous extraction with benzene.[16b]

In a study of the catalytic effect of various sulfates and oxides upon the rate of sulfonation of benzene at 242–260° by 70% acid [17] the most active catalyst was found to be a mixture of sodium sulfate and vanadium pentoxide. Benzene and other hydrocarbons are sulfonated quantitatively at room temperature by an excess of sulfuric acid in the presence of dry infusorial earth or animal charcoal.[18] Benzenesulfonic acid is one of the products obtained in the action of iodine and sulfuric acid upon benzene at 170–180°. It also results from heating sulfuric acid and iodobenzene.[19] The ready conversion of diphenylmercury to mercuric benzenesulfonate by sulfur trioxide [20] may explain the catalytic effects of mercury salts in certain sulfonation reactions mentioned later. The catalytic effects of other substances have been investigated for the sulfonation of a variety of compounds. These effects are discussed in later sections.

Benzene is monosulfonated readily at ordinary temperatures by sulfuric acid containing 5–9.5% sulfur trioxide [21] without appreciable formation of disulfonic acids. Monosulfonation by direct action of sulfur trioxide in the liquid state is not satisfactory because of side reactions, but if sulfur trioxide is passed into a chloroform solution [9,10] of the hydrocarbon at 0–10° a 90% yield of the monosulfonic acid is obtainable. Sulfur dioxide has also [22a,b,d] been suggested as a solvent for this reaction. Dioxane sulfotrioxide reacts slowly at room temperature to give a high yield of benzenesulfonic acid.[22c] Sulfonation of benzene in the vapor phase with sulfur trioxide [22d,23a] has been patented as a method for preparing phenyl sulfone and other similar compounds. Under reduced pressure a mixture of products is obtained.[23b]

Refluxing benzene with sodium trihydrogen disulfate [24] results in a slow formation of sodium benzenesulfonate. Undoubtedly the insolubility of the salt in the hydrocarbon is partly responsible for the low rate of the reaction.

Chlorosulfonic acid is a very active sulfonating agent. When benzene is added to an excess of this at room temperature benzenesulfonyl chloride [25] is formed in 70% yields. Only a trace of phenyl sulfone is produced, but if an excess of benzene is present [26] benzenesulfonic acid and the sulfone are the principal products.

Fluorosulfonic acid [27] behaves much as its chlorine analog except that it reacts somewhat less vigorously. By adding 55 g. of benzene to 225 g. of fluorosulfonic acid at 16–20° a 62% yield of benzenesulfonyl fluoride is obtained.[27a] Nitryl sulfate, $(O_2NOSO_2OSO_2)_2$, reacts with benzene to give in addition to other products some benzenesulfonic acid.[28]

Benzenesulfonic acid may be obtained in a pure state by crystallization from chloroform.[2] It melts at 52–53° and distils only in a high vacuum.

Disulfonation of Benzene. Sulfonation of benzene to the disulfonic acids has been exhaustively investigated,[29] both with reference to the reaction conditions and the amounts of the various isomers produced. Benzene with twice its volume of 20% oleum[30] gives only the *m*-disulfonic acid as determined by the freezing point of the disulfonyl chloride prepared from the reaction product. Whenever less vigorous sulfonating agents which require longer reaction times are used the formation of the *para* isomer becomes important. This is shown in Table I. Heating barium benzene-*p*-disulfonate with 98% sulfuric acid slowly converts it into the *meta* isomer. This observation indicates that the mechanism of formation of the *para* from the *meta* compound involves hydrolysis and resulfonation. It has also been found that benzenesulfonic acid is converted to a mixture of disulfonic acids by heating at 210–275° with sulfuric acid under reduced pressure (60 mm.).[31a] The water distils readily enough to keep the concentration of sulfuric acid at a value that permits sulfonation to proceed.

TABLE I

SULFONATION OF BARIUM BENZENESULFONATE AT 209°

Conc. of Acid		Time, Hours					
		4	6	18	24	30	48
98%	*p*-isomer, %	= 11.1	10.0	13.7	16.1	15.1	22.7
12.5% SO_3	*p*-isomer, %	= 2.0	3.0	3.0	7.1	6.1	....

Instead of treating benzene directly with oleum, disulfonation may be effected by introducing one sulfo group with sulfuric acid followed by passing sulfur trioxide into the reaction mixture[31b] to complete the reaction. Any unreacted acid may then be utilized in further monosulfonation. Allowing benzene to react with sulfur trioxide in an inert solvent such as sulfur dioxide[22b] to effect the entrance of one sulfo group followed by evaporation of the solvent and the addition of more sulfur trioxide is also a feasible method for making the *m*-disulfonic acid.

A number of compounds show a catalytic influence in the sulfonation of benzenesulfonic acid. Under conditions where 100% sulfuric acid with no catalyst gives only 0.87% of benzene-*p*-disulfonic acid, the presence of 1% of mercury[32] as sulfate produces a 30.8% yield; likewise ordinary sulfuric acid with a mercury catalyst gives a 32.6% yield[33,34] at 235–245°. The sulfates of cadmium, aluminum, lead, arsenic, bismuth, and iron also have marked effects. Manganous sulfate has a small effect. In the presence of selenium, carbonization occurs and no disulfonated compounds were isolated.

A study of the conditions necessary for obtaining a high yield of mixed disulfonates when 95% sulfuric acid is the reagent indicates that the use of a 150% excess of acid in the presence of 0.1% of sodium (as sulfate) at a temperature of 250° is the most efficient set of conditions.[35] Both sodium sulfate and vanadium pentoxide exert considerable effect in increasing the yield of disulfonates and decreasing the time required. For the conditions given above the sodium sulfate increased the yield of product from 78.5 to 92% for a reaction time of 1 hour, while vanadium pentoxide gave an 84.5% yield. The extent of the formation of the *para* isomer was not determined for these reaction conditions. Disulfonation of benzene with sodium trihydrogen sulfate had been patented[36] much earlier.

By dissolving benzene in ten parts of chlorosulfonic acid and then heating at 150–160° for 2 hours[37] there are formed *m*-benzenedisulfonyl chloride (10.3 g. from 10 g. of benzene), a small amount of the *para* isomer and some (phenyl sulfone)-disulfonyl chloride. This latter may be made the chief product by varying the reaction conditions suitably.

Trisulfonation of Benzene. Benzene-1,3,5-trisulfonic acid has been prepared by several procedures. Benzene and sulfuric acid in the presence of phosphorus pentoxide[38] at 280–290° give this reaction product. Potassium benzene-*m*-disulfonate when heated with sulfuric acid to a high temperature,[39] or benzene-*m*-disulfonic acid with sodium trihydrogen sulfate[36] at 280–300° also gives the trisulfonated compound. Probably the most satisfactory procedure involves the sulfonation of sodium benzene-*m*-disulfonate with oleum in the presence of mercury at 275°.[32,40]

Monosulfonation of Toluene. Many of the monoalkyl derivatives of benzene have been sulfonated, but only for toluene has this reaction been investigated in detail. Jaworsky[41] first prepared the mixed sulfonic acids, from which the two isomers were later separated,[42] by sulfonation of toluene with sulfuric acid. The structures of the two isomers were determined by fusion with alkali.[43] There was considerable controversy among some of the earlier investigators[44] regarding the presence of *m*-toluenesulfonic acid as one of the sulfonation products. Later work seems to indicate that a small percentage of this isomer is usually formed; the evidence consists in the isolation of the 2,5-disulfonic acid in the disulfonation of toluene[45] and the melting points of mixtures of the sulfonyl chlorides[46] obtained from monosulfonation products, rather than in an actual isolation of the sulfonic acid. The *meta* isomer seems to be formed directly from toluene rather than by rearrangement of either of the other isomers, and it does not change into either of them when heated at 100° with sulfuric acid. On the other hand, the *ortho* and *para* isomers show slow interconversion even at 75°.

Toluene sulfonates somewhat more readily than does benzene, 96–100% sulfuric acid reacting readily at 35°, and even at 0° at an appreciable rate[46] although at this temperature the acid needed to complete the sulfonation is somewhat more than six times the weight of the toluene used. Variation of the concentration of the acid over the range 96–100% has no effect upon the percentage of each isomer produced but this is influenced by the reaction temperature and the excess of acid used. The *para* isomer is formed in larger amounts at the higher temperatures, at 75° the composition of the reaction product being 75% *para,* 6% *meta,* and 19% *ortho* isomers. Addition of silver, mercurous, or potassium sulfate has no appreciable influence[47] upon the percentages of the isomers, either with sulfuric acid or oleum. The results obtained with oleum[47,48a] are not greatly different than those with the concentrated acid, Holdermann[47] reporting a mixture of 69% *para* and 31% *ortho* isomers from sulfonation with oleum. For the quantitative sulfonation of toluene in "petroleum toluene" 3% oleum is most satisfactory.[48b] Two volumes of acid to one of the petroleum fraction were used. The reaction was complete in 15 minutes.

Toluenesulfonic acids have been prepared by passing toluene vapor through sulfuric acid as already described[49a] for benzene (see p. 199), and by long refluxing of toluene with sodium trihydrogen disulfate.[24] The electrochemical sulfonation of toluene in alcohol claimed by Puls[49b] does not occur.[49c] The separation of toluene from petroleum fractions has been accomplished by sulfonation with sulfuric acid[49d] at 60°.

By sulfonating toluene with gaseous sulfur trioxide[49e] at 40–55° there results a mixture containing 20–24% of the *p*-sulfone, and 7.9–8.5% of the *ortho*, 54–56% of the *para*, and 6–7% of the *meta* sulfonic acids. The *meta* acid was not found in experiments where phosphorus pentoxide or acetic anhydride was present in the reaction mixture.

In the first use of chlorosulfonic acid[50] the formation of *p*-toluenesulfonic acid and *p*-tolyl sulfone were reported, and mention made of the possibility of some *o*-toluenesulfonic acid being present. In a comparison of the sulfonating action[46] of chlorosulfonic and sulfuric acids at 35° the results shown in Table II were obtained. The product obtained by adding 60 g. of toluene to 150 g. of chlorosulfonic acid at 10° is chiefly a mixture of the acid chlorides,[44e, 51] an 8% yield of toluenesulfonic acids remaining in the water soluble portion of the reaction mixture.

TABLE II

SULFONATING AGENT	*para* ACID, %	*meta* ACID, %	*ortho* ACID, %
Chlorosulfonic acid	58.8	3.8	37.5
Sulfuric acid	63.1	6.3	30.6

The mechanism of the sulfonating action of chlorosulfonic acid has been reviewed and further investigated by Harding.[52] There can hardly be any doubt that sulfonic acid formation precedes the appearance of the sulfonyl chlorides in reactions involving this reagent.

$$CH_3C_6H_5 + ClSO_3H \rightarrow CH_3C_6H_4SO_3H + HCl$$

$$CH_3C_6H_4SO_3H + ClSO_3H \rightarrow CH_3C_6H_4SO_2Cl + H_2SO_4$$

Harding was able to obtain as high as 95% yields of the *p*-toluenesulfonyl chloride at 75–80°, lower temperatures favoring *ortho* sulfonation. The percentages of *ortho* and *para* isomers present were estimated by conversion of the chlorides into the amides and determining the melting points of the mixtures.[53] These results are of considerable technical interest as the *ortho* isomer is the one required in the manufacture of saccharin.

The complex reaction between chlorosulfonic anhydride and toluene has been investigated in some detail.[54] At 60° a great deal of hydrogen chloride and somewhat less sulfur dioxide are evolved, the sulfonation products including *p*-toluenesulfonic acid, a chlorosulfone, *p*-toluenesulfonyl chloride, and a mixture of some isomeric dichlorotoluenes. The sulfonic acid and sulfonyl chloride may be accounted for by the equations listed below.

$$2C_6H_5CH_3 + S_2O_5Cl_2 \rightarrow (CH_3C_6H_4SO_2)_2O + 2HCl$$

$$(CH_3C_6H_4SO_2)_2O + HCl \rightarrow CH_3C_6H_4SO_2Cl + CH_3C_6H_4SO_3H$$

or

$$2C_6H_5CH_3 + S_2O_5Cl_2 \rightarrow 2CH_3C_6H_4SO_2Cl + H_2O$$

$$S_2O_5Cl_2 + 3H_2O \rightarrow 2H_2SO_4 + 2HCl$$

$$C_6H_5CH_3 + H_2SO_4 \rightarrow CH_3C_6H_4SO_3H + H_2O$$

If the first equation is correct, the chlorosulfonic anhydride reacts in the same manner as does chlorosulfonic acid. In the presence of aluminum chloride reaction occurs even below 0° with formation of *p*-toluenesulfonic acid, *p*-tolyl sulfone, and chlorotoluenes.

Excess fluorosulfonic acid[27a] at ordinary temperatures gives an 89% yield of a mixture of the toluene sulfonyl fluorides of which about 40% is the *ortho* isomer.

Di- and Trisulfonation of Toluene. Sulfonation of toluene at a high temperature with oleum[55] gives toluene-2,4-disulfonic acid as the main product together with a little of the 2,5-isomer. Since this latter is not obtained from *o*- or *p*-toluenesulfonic acid it indicates that *m*-toluenesulfonic acid is one of the primary sulfonation products, since further sulfonation converts it into a mixture of the 2,5- and 3,5-disulfonic acids.[56] It would be of interest to study the sulfonation of toluene under conditions which have been found to give the *sym*-disulfonic acids with chloro- and bromobenzene (see p. 214).

Sulfonation of *p*-toluenesulfonyl chloride with oleum[44, 57a] at 140–150° gives an excellent yield of the 2,4-disulfonic acid, hydrogen chloride being evolved. *o*-Toluenesulfonyl chloride may be sulfonated without hydrolysis occurring.[57b] Heating toluene with eight parts of chlorosulfonic acid at 140–150° produces a high yield of the 2,4-disulfonyl chloride.[37] No mention was made of an isomeric product. By changing the conditions suitably (*p*-tolyl sulfone)-disulfonyl chloride is formed in large amounts. Heating the mixture of *o*- and *p*-toluenesulfonyl fluorides already referred to with more fluorosulfonic acid at 130–140° for 3 hours results in a 48% yield of the 2,4-disulfonyl fluoride.[27a]

Sulfonation of the potassium 2,4-disulfonate with three molecular equivalents of chlorosulfonic acid at 240° gives the 2,4,6-trisulfonic acid.[58]

Sulfonation of Higher Alkylbenzenes. In marked contrast with the behavior of toluene, ethylbenzene with sulfuric acid,[59] oleum,[60, 61] or chlorosulfonic acid yields only the *p*-sulfonic acid. This is in accord with the observation that the *ortho* isomer, prepared in an indirect manner, rearranges[61] rapidly upon heating at 100° into the *para* compound. This reaction has apparently not been studied for the higher alkylbenzene-*o*-sulfonic acids. With 50% oleum[62] ethylbenzene is converted into the 2,4-disulfonic acid. By standing with four parts of fluorosulfonic acid[63] an 86% yield of the 4-sulfonyl fluoride was obtained, together with a small amount of the sulfone.

Sulfonation of *n*-propylbenzene with sulfuric acid[64] or oleum,[65, 66] isopropylbenzene with sulfuric acid[67] or oleum,[65, 68] and *n*-butylbenzene with oleum[60] give small but definite amounts of the *ortho* isomers together with high yields of the *p*-sulfonic acids. By the action of sulfuric acid containing small amounts of sulfur trioxide, *sec*-butylbenzene,[70] *tert*-butylbenzene,[71] several isomeric amylbenzenes,[72,73] and hexylbenzenes,[74a,b,c,d] and *n*-octylbenzene[74e] are converted into sulfonic acids which are undoubtedly the *para* isomers. This, however, has not been formally demonstrated except in the case of neopentylbenzene[73] where a 95% yield of the *p*-sulfonic acid was obtained. Oxidation gave the corresponding benzoic acid. If any *ortho* isomers are formed in the preceding sulfonations they are present in small quantities. *n*-Hexadecyl and *n*-octadecylbenzenes with oleum[75a] likewise give the *p*-sulfonic acids. Here the structures of the compounds were proved by alkali fusion. These higher alkylbenzenesulfonic acids are excellent reagents for the hydrolysis of fats.[75b]

Several alicyclic derivatives of benzene have been sulfonated. Cyclohexylbenzene with oleum[75c] in excess is converted into the 4-sulfonic acid. 3-Methylcyclopentylbenzene, $CH_3C_5H_8C_6H_5$, has also been sulfonated with oleum.[75d] Only one sulfonic acid was reported in each instance. Bornylbenzene is sulfonated quantitatively by the action of sulfuric acid at room temperature.[75e] The sulfo group is in all probability in the *para* position in the benzene ring.

Numerous alkylbenzenesulfonic acid salts have been patented as washing or emulsifying agents.[76] In general the commercial products are mixtures obtained by the sulfonation of mixed *sec*-alkylbenzenes which in turn have been prepared by the action of a mixture of olefins or alkyl chlorides with benzene in the presence of a condensing agent, usually aluminum chloride or sulfuric acid. An exception is the sulfonation product of laurylbenzene[76b] which was prepared from laurophenone by reduction. In this instance sulfonation was effected by chlorosulfonic acid or oleum in ethylene chloride solution. The alkyl group may contain substituents as in the product obtained by condensing oleone[76c] or oleic acid[76f] with benzene and sulfonating the product.[76c]

In a number of instances[76i,j] the alkylbenzenesulfonic acids have been obtained by alkylation of benzene, toluene, or xylenesulfonic acids. This is surprising as *meta*-directing groups prevent the occurrence of reactions of the Friedel-Crafts type. However, Desseigne[76k] has shown that *p*-toluenesulfonic acid condenses with isopropyl alcohol readily in 93% sulfuric acid at 40°. After removal of the sulfo groups by acid hydrolysis *o*-cymene and 2,6-diisopropyltoluene were obtained in about equal amounts. Even the presence of a nitro group did not prevent the condensation.

The sulfonation reactions of a variety of benzylsilicanes [77] should be mentioned here since they are closely related to simple alkylbenzenes. Sulfonation of benzyltrimethylsilicane, for example, with chlorosulfonic acid in chloroform gives the *p*-sulfonic acid without disturbing the silicon-containing side chain.

SULFONATION OF THE DIALKYLBENZENES

With the Alkyl Groups Identical. Pure compounds are readily obtained in the sulfonation of these dialkylbenzenes since, with two exceptions, only one monosulfonic acid results regardless of the nature or position of the alkyl groups.

o-Xylene is converted into the 4-sulfonic acid by warming with an equal volume of sulfuric acid.[78a] In the presence of 2% and 10% of mercury (as sulfate), however, there is formed 8% and 22% respectively of the 3-sulfonic acid.[34] Shaking 20 ml. of the hydrocarbon with 24 ml. of sulfuric acid [78b] at room temperature sulfonates 68% in 0.5 hour and 82% in 2 hours. The 3-sulfonic acid rearranges into the 4-isomer either from heating alone [79] or in sulfuric acid solution.[78b] Separation of the *o*-xylenesulfonic acid from the products obtained in the sulfonation of a mixture of the xylenes is readily feasible by taking advantage of the difference in solubilities of the calcium or sodium [80] salts of the isomeric acids.

Sulfonation of barium *o*-xylene-*p*-sulfonate with twice its weight of chlorosulfonic acid [81] at 150° gives a disulfonic acid whose structure was not determined. That it is the 3,5-disulfo compound seems very probable, however, as an excess of chlorosulfonic acid [37] converts *o*-xylene into the 3,5-disulfonyl chloride.

Sulfonation of *m*-xylene with sulfuric acid [82] occurs somewhat more readily [83] than for the *ortho* and *para* isomers. Either sulfuric acid or oleum [84,85] produces the 4-sulfonic acid as the sole or chief product. The 2-sulfonic acid readily undergoes rearrangement [85] to the 4-isomer so would hardly be expected as a product of a high-temperature sulfonation. It has been isolated in small amounts from the product obtained in the sulfonation of *m*-xylene at room temperature with sulfuric acid.[86]

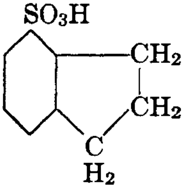
An excess of fluorosulfonic acid [27a] at room temperature converts *m*-xylene into the 4-sulfonyl fluoride. This by heating to 100° with more of the reagent is claimed to give a 70% yield of the 2,4-disulfonyl fluoride. This structure seems unlikely in light of the behavior of other sulfonating agents which give the 4,6-compound. Heating *m*-xylene with pyrosulfuric acid forms a disulfonic acid which was at first also believed to be the 2,4-isomer[87] since its properties were similar to those of the acid obtained by reduction of 6-bromo-*m*-xylene-2,4-disulfonic acid with zinc and ammonium hydroxide. Likewise, treatment with phosphorus pentachloride and fusion with alkali yields 2,4-compounds. Sulfonation of the 2- and 4-sulfonic acids[81] produces the same compound. More recent investigations[86, 88, 89] have shown, however, that this disulfonic acid and the corresponding disulfonyl chloride obtained when chlorosulfonic acid is the sulfonating agent are actually the 4,6-isomers. The reactions which led to assigning the 2,4-structure have all been satisfactorily explained by rearrangements.

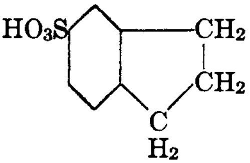
p-Xylene is more difficult to sulfonate[90] than its two isomers. Under comparable conditions 68% of a sample of *p*-xylene dissolved in sulfuric acid while 82% of the *ortho* isomer reacted.[78b] The monosulfonic acid has also been prepared by the action of oleum of various concentrations.[91] With acid containing 25% sulfur trioxide a high yield of the crystalline sulfonic acid results by pouring the reaction mixture into a small volume of water. With fluorosulfonic acid in excess at 25°, *p*-xylene gives an 85% yield of the sulfonyl fluoride.[27a] Disulfonation does not occur as it does for *m*-xylene.

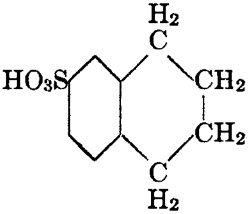
Heating *p*-xylene with 50% fuming sulfuric acid at 140–150° produces the 2,6-disulfonic acid[92] as the chief product. The action of an excess of chlorosulfonic acid[88] results in the formation of the 2,6- and 2,5-disulfonyl chlorides in a ratio of 10 to 1; *p*-xylyl sulfone is an important by-product.[37] None of the 2,3-isomer was found. A disulfonic acid which is probably the 2,6-compound results from treatment of *p*-xylenesulfonyl chloride with sulfuric acid.[93]

Sulfonation of the other dialkylbenzenes gives sulfonic acids which are analogous in structure to those obtained from the xylenes except that two sulfonic acids have not been isolated from the *meta* compounds as in the case of *m*-xylene. Although generally the structures of the acids obtained have not been established by independent syntheses they can be inferred by analogy with the corresponding xylene derivatives. These remarks apply to the monosulfonation of *ortho*,[94] *meta*,[95] and *para*[96] diethylbenzenes, *p*-di-*n*-propylbenzene,[97] *ortho*[98] and *m*-diisopropylbenzene,[98] and *p*-di-*tert*-butylbenzene.[99a] The dipropylbenzene disulfonated with oleum by Heise[99b] is of uncertain structure as the hydrocarbon was obtained by the action of aluminum chloride upon *n*-propylbenzene.

From the standpoint of their reaction toward sulfonating agents hydrindene and tetralin may well be included here. Shaking hydrindene with two parts of sulfuric acid[100a] converts it into a mixture of two monosulfonic acids, I and II, of which II is the less soluble in water.


I


II


III

Tetralin with sulfuric acid[100b,c] gives almost entirely the 2-sulfonic acid (III) which crystallizes from water as the dihydrate. With chlorosulfonic acid[100c] both possible sulfonic acids result; these are separable by crystallization of the less soluble 1-sulfo compound from chloroform or its lead salt from water. When 180 g. of tetralin stands with 730 g. of fluorosulfonic acid[27a] at 15–20° for 12 hours, the 1-sulfonyl fluoride is produced in 12–16% yields.

1,1-Dimethyltetralin monosulfonates readily when treated with an equal volume of sulfuric acid[100d] at 90° for 2 hours. Ionene (1,1,6-trimethyltetralin) behaves similarly.[100e] This probably gives the 7-sulfonic acid as 6-methyltetralin gives the 7-sulfonated compound.[100f]

With Unlike Alkyl Groups. A detailed knowledge of the sulfonation products obtained from the dialkylbenzenes containing unlike alkyl groups would be of interest in determining alkyl directive influences, but unfortunately in most reactions the structures of the isomeric sulfonic acids formed have not been established. Except in the case of *p*-cymene, even where the structures of the acids are known, the relative amounts of the isomers obtained have not been accurately determined. What evidence there is indicates that the methyl group has a greater *ortho* directive influence than *n*-propyl or isopropyl, and that this difference becomes more pronounced when methyl is compared with the higher alkyl groups. It has been found in several reactions that of two isomeric sulfonic acids the one formed in larger amount gives a barium salt much less soluble in water than that of the isomer.

The *ortho,*[101] *meta,*[102] and *para*[103,104] ethyltoluenes are each sulfonated by sulfuric acid or weak oleum to a mixture of two isomeric sulfonic acids whose structures are unknown. For the *ortho* and *para* compounds one sulfonic acid is produced in much larger quantity than the other.

Meta[105] and *para*[103,106] *n*-propyltoluenes have likewise each been shown to give a pair of isomeric sulfonic acids; separation was accomplished by differences in solubilities of the barium salts. For the *para* compound the structures were determined and the compound containing the sulfo group *ortho* to methyl was found to be the principal product. Sulfonation of *o*-isopropyltoluene with oleum [107] at 50° gives two acids of unknown constitution but for *m*-isopropyltoluene in the sulfonation with sulfuric acid [108] the structures are known,[109] the chief product being 3-isopropyltoluene-6-sulfonic acid. Separation was again accomplished by the much greater solubility in water of the barium salt of the minor product, 1-methyl-3-isopropylbenzene-4-sulfonic acid.

The sulfonation of *p*-isopropyltoluene(*p*-cymene) has been investigated in some detail. Early workers [110] assumed the presence of only one monosulfonic acid and a search for a second isomer by Jacobsen [111] was unsuccessful. Soon thereafter,[112] however, the barium salt of a second acid was isolated from the product obtained by sulfonating the hydrocarbon with sulfuric acid at 100°. The yield of this was later [113] given as 14.6% for these conditions. The isomer produced in lesser quantity gives thymol upon fusion with alkali [114] and hence is 1-methyl-4-isopropylbenzene-3-sulfonic acid. It would be of interest to learn the relative directive influence of the two alkyl groups in *o*-isopropyltoluene. Careful studies [115, 116] of the sulfonation of *p*-cymene with sulfuric acid at various temperatures and also with 15% oleum showed that the best yield (15.6%) of the 3-sulfonic acid was obtained by the action of sulfuric acid at 100° with a 1 to 3 ratio of hydrocarbon to acid. At 0° with oleum the yield of this isomer dropped to 2.5%, a 90% yield of the barium salt of the principal acid being recoverable. Above 100° the formation of disulfonic acids becomes important. The addition of potassium, silver, cobaltous, or nickelous sulfates to the sulfonation mixture did not change the amount of 3-sulfonic acid formed when sulfuric acid was the reagent while cupric and mercuric sulfates decreased it from 15.6% to 9.4% and 9.7% respectively. From 2.8 molecular equivalents of sulfuric acid [117] substantially the same results were obtained as in Phillip's work,[115] never more than 20% of the 3-isomer resulting. Isolation of the 2-sulfonic acid as the magnesium salt has been patented.[118] Chlorosulfonic acid [116] gives the 2-sulfonyl chloride as the chief product.

With sulfuric acid [119, 120] or oleum [121] *m*-*tert*-butyltoluene gives only one sulfonic acid, the sulfo group undoubtedly being *ortho* to methyl and *para* to *tert*-butyl. The "*p*-butyltoluene" sulfonated by Kelbe and Baur [119] may have been *p*-cymene.[122]

Sulfonation of 1-ethyl-4-*n*-propylbenzene with sulfuric acid [123] at 100° yields the two possible isomers; their structures were determined by oxidation of the sulfonamides. For 1-ethyl-3-isopropylbenzene,[124] 1-ethyl-4-isopropylbenzene,[125] *p*-isoamyltoluene,[126] and a *tert*-butylethylbenzene [90] of unknown structure only one acid was reported. One would expect the sulfo group to occupy a position *ortho* to the small alkyl group in each compound. This is probably also true for *p*-*n*-octyltoluene [127a] and *p*-*n*-hexadecyltoluene [127b] which are readily sulfonated by oleum. 1-*n*-Propyl-4-isopropylbenzene,[128] on the other hand, gives both isomers. The structures of these were not determined, however.

3-Cyclohexyltoluene reacts readily with sulfuric acid [129] to give what is probably the 6-sulfonic acid.

Sulfonation of Trialkylbenzenes

Of the trialkylbenzenes, sulfonation of the trimethyl compounds has been most thoroughly studied. 1,2,3-Trimethylbenzene [130] (hemimellithene) dissolves readily in sulfuric acid to give the 4-sulfonic acid.[131] 1,2,4-Trimethylbenzene (pseudocumene) likewise gives only one monosulfonation product,[132] the 5-sulfonic acid. Using sulfuryl chloride [133] and aluminum chloride produces the corresponding 5-sulfonyl chloride as one of the products. The action of fluorosulfonic acid [27a] yields a sulfonyl fluoride.

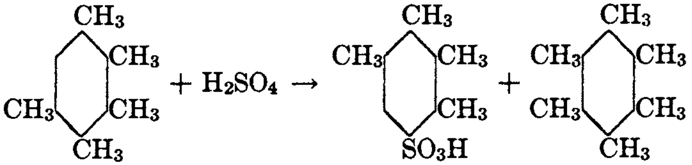
1,3,5-Trimethylbenzene (mesitylene) monosulfonates readily [132h,134] with sulfuric acid.[135] Oleum has been employed in one instance [136] to form this sulfonic acid, and sulfuryl chloride [133] with aluminum chloride gives some of the sulfonyl chloride. By heating 40 g. of mesitylene with 400 g. each of sulfuryl chloride and chlorosulfonic acid [137] at 100° for 10 hours a high yield of the disulfonyl chloride is obtained. This compound also results in 70% yield when mesitylene reacts with chlorosulfonic acid [137b] at $-5°$. Fluorosulfonic acid [27a] gives a sulfonyl fluoride which with chlorosulfonic acid sulfonates further and exchanges fluorine for chlorine to yield the disulfonyl chloride. The disulfonic acid reacts with sulfur trioxide [137b] at 120° to give a small yield of the trisulfonic acid.

1,2,4-Triethylbenzene upon treatment with oleum [138] gives only one sulfonic acid. By analogy with the structure of the acid obtained from the methyl compound this should be the 5-isomer. 1,3,5-Triethylbenzene [138] and 1,3,5-triisopropylbenzene [139] have also been monosulfonated. Of the trialkylbenzenes containing more than one kind of alkyl group, 1,4-dimethyl-2-ethylbenzene [130b,140] 1,5-dimethyl-2-ethylbenzene,[130b,132a] 1,2-dimethyl-4-*n*-propylbenzene,[141] 1,4-dimethyl-2-*n*-

propylbenzene,[141] 1,5-dimethyl-2-*n*-propylbenzene,[141] 1,5-dimethyl-2-isopropylbenzene,[141] 1,3-dimethyl-5-*tert*-butylbenzene,[27a,142] 1-methyl-2-*n*-propyl-4-isopropylbenzene,[143] and 1-methyl-3,5-diisopropylbenzene yield one monosulfonic acid whereas from 1,2-dimethyl-4-ethylbenzene[130b,140,144] and 1,2-dimethyl-4-isopropylbenzene two isomers are obtained. None of these structures is known. Sulfonation of 1,3-dimethyl-5-ethylbenzene[145] has been found to yield only the 2-sulfonic acid.

SULFONATION OF POLYALKYLBENZENES

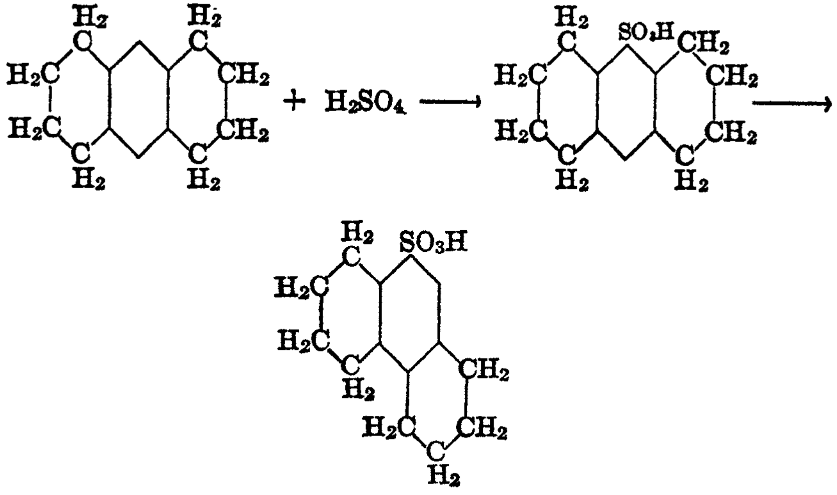
Sulfonation of several tetra- and pentaalkylbenzenes is complicated by the occurrence of rearrangements, the so-called Jacobsen reaction.[146,147] 1,2,3,4-Tetramethylbenzene (prehnitene) sulfonates readily[132c,148] with no shift of the methyl groups. The same product is formed by the action of sulfuric acid[146,147] upon pentamethylbenzene. The mechanism of this reaction involves the disproportionation of pentamethylbenzenesulfonic acid[147] which is accompanied by side reactions. The sulfonic acids obtained from 1,2,3,5-tetramethylbenzene (isodurene) and 1,2,4,5-tetramethylbenzene (durene) rearrange[132h] either in a desiccator over or mixed with phosphorus pentoxide, or upon standing with sulfuric acid, to give chiefly 1,2,3,4-tetramethylbenzenesulfonic acid. These reactions are accompanied by a copious evolution of sulfur dioxide, about 0.34 mole being formed for every mole of durene or durenesulfonic acid used; a brown amorphous material and a black sulfonic acid were also isolated. Sulfonation of a mixture of durene and isodurene is the most convenient source of prehnitenesulfonic acid so far discovered, and by hydrolysis, for the hydrocarbon itself.



Since the rearrangement reactions of the durene and isodurenesulfonic acids are comparatively slow, about twenty-five days being required for them to go to completion at room temperature, the sulfonic acids of these hydrocarbons are readily prepared. 1,2,3,5-Tetramethylbenzenesulfonic acid has been obtained by action of either fuming[132c,149] or concentrated[132h] sulfuric acid upon the hydrocarbon. The isomeric 1,2,4,5-compound has been sulfonated with fuming sulfuric acid[182h,150] and chlorosulfonic acid.[148,151] In the chlorosulfonic acid reaction some of the sulfonyl chloride is also formed.

The sulfonic acid obtained from ethylmesitylene and oleum[125,152a] has the unrearranged structure, but with sulfuric acid at 60–70° after 6 hours only rearranged products remain.[152b] The reaction is complex since hydrolysis of the sulfonic acids yields mesitylene, 1,3-dimethyl-2-ethylbenzene, 1,2,3,4-tetramethylbenzene (prehnitene) as well as 1,2,4-trimethyl-3-ethylbenzene (3-ethylpseudocumene), the main product. 1,2,4-Trimethyl-5-ethylbenzene sulfonates less readily than ethylmesitylene but the sulfonic acid rearranges much more rapidly.[152b,158] Oleum[125] and chlorosulfonic acid[152b] yield an unrearranged sulfonic acid. 1,2,4-Trimethyl-3-ethylbenzene does not undergo the Jacobsen reaction. 1,3,5-Trimethyl-2-*n*-propylbenzene,[152,154a] 1,3,5-trimethyl-2-*n*-heptylbenzene[154a] and 1,2,4,5-tetraethylbenzene[154b,c] have been sulfonated, but only in the last case was there evidence of rearrangement. 1,2,3,4-Tetraethylbenzenesulfonic acid and hexaethylbenzene result from sulfonation[154b,155] of pentaethylbenzene. Although pentamethylbenzene undergoes the Jacobsen reaction it is possible to prepare the sulfonic acid[146,147] if this is not allowed to stand too long with the sulfonating agent.

It is interesting to note at this point that octahydroanthracene behaves in a manner exactly analogous to 1,2,4,5-tetramethylbenzene. By short sulfonation with sulfuric acid the sulfonic acid results but upon standing with the sulfonating agent rearrangement occurs[156a] as indicated by the equation. The final product may also be prepared by sulfonation of octanthrene[156b] (octahydrophenanthrene).



SULFONATION OF HALOGEN DERIVATIVES OF BENZENE

Three generalizations may be made about the sulfonation reactions of the halobenzenes. (1) Sulfonation occurs with more difficulty than for the unsubstituted hydrocarbon. (2) The directive influence of any halogen is strongly *para*. Only when the *para* position is not open does an *ortho* isomer result, except when a mercury catalyst is used. (3) Sulfonating agents which react slowly with bromo and particularly with iodo compounds frequently bring about a removal or redistribution of the halogen atoms. As an extreme case, *p*-diiodobenzene cannot be satisfactorily sulfonated with any reagent so far investigated; even with sulfur trioxide the products are polyiodobenzenes and a mixture of sulfonic acids. These halogens change places more readily than do methyl groups in the Jacobsen reaction. Too little is known concerning the two reactions to decide whether or not they have a common mechanism.

Sulfonation of Monohalobenzenes. Sulfonation of fluorobenzene[157a] with 10% oleum at a maximum temperature of 70° occurs readily with formation of the 4-sulfonic acid. This was isolated as the barium or ammonium salt. Chlorosulfonic acid at 50° gives the sulfone unless a solvent is present; then the *p*-sulfonyl chloride is formed.[157b]

Chlorobenzene reacts with sulfuric acid[2,158] slowly even at 100°, and reacts with oleum[159] of various concentrations at lower temperatures. The reaction proceeds best with enough 10% oleum to contain one mole of sulfur trioxide per mole of chlorobenzene[160] and at a reaction temperature not above 60°. By reaction with an equimolecular quantity of chlorosulfonic acid,[161] small amounts of the 4-sulfonyl chloride and sulfone are formed in addition to the sulfonic acid. By the use of an excess of the sulfonating agent,[157b,162] preferably at 25°,[163] or a mixture also containing oleum, the 4-chlorobenzenesulfonyl chloride is obtained in good yields. This acid chloride is further sulfonated by 100% sulfuric acid[164,165] at 160–180° to chlorobenzene-2,4-disulfonic acid, and by chlorosulfonic acid[37] at 150–180° to the 2,4-disulfonyl chloride. Interestingly enough, chlorobenzene, the 4-sulfonic acid, or the 2,4-disulfonic acid, when heated to 300° with 20% oleum[165,166] gives chiefly the 3,5-disulfonic acid. This may be considered analogous to the abnormal halogenation in the *meta* position to groups ordinarily *ortho-para* directing which has been found by Wibaut[167] to occur at high temperatures in the vapor phase.

From refluxing bromobenzene with ten times its weight of sulfuric acid[168] a complex mixture of products results. These include 3,5-dibromobenzenesulfonic acid, two isomeric bromobenzenedisulfonic acids, *p*-dibromobenzene, 1,2,4,5-tetrabromobenzene, and hexabromobenzene. The formation of these compounds may be due to oxidation of part of the bromobenzene to give bromine or hypobromous acid which then brominates both the sulfonated and unsulfonated compounds. The presence of 3,5-dibromobenzenesulfonic acid suggests that the following reactions may occur.

$$C_6H_5Br + H_2SO_4 \rightarrow C_6H_5SO_3H + HOBr$$

$$C_6H_5SO_3H + HOBr \rightarrow m\text{-}BrC_6H_4SO_3H + H_2O$$

$$C_6H_5Br + HOBr \rightarrow p\text{-}C_6H_4Br_2 + H_2O$$

Carbon monoxide was found in the gases evolved during the reaction. A quantitative study would undoubtedly aid in formulating a more satisfactory mechanism for the complex changes that occur. With oleum[160, 169] the sulfonation proceeds normally to form the 4-sulfonic acid and a little *bis*-(*p*-bromophenyl) sulfone.[170] Chlorosulfonic acid[157b] in carbon disulfide solution has been shown[161, 169d, 171] to give the same products. Sulfonation to the 2,4-disulfonic acid results from the action of sulfur trioxide[169c] at 200–220° or of pyrosulfuric acid[172] at 220–240°. As with chlorobenzene, oleum[173] at 300° gives the 3,5-disulfonic acid.

Iodobenzene with sulfuric acid[174] or oleum[160, 174, 175, 176] yields the 4-sulfonic acid and *bis*-(4-iodophenyl) sulfone. At high temperatures, even noticeably at 100°, side reactions occur[174] with formation of *p*-diiodobenzene and benzenesulfonic acid. As would be expected, this occurs more readily than with bromobenzene.

$$2C_6H_5I + H_2SO_4 \rightarrow C_6H_4I_2 + C_6H_5SO_3H + H_2O$$

The best yield of diiodobenzene (20 g. from 50 g. of iodobenzene) results from heating equal weights of iodobenzene and sulfuric acid at 170–180° for 2 hours. Barium *p*-iodobenzenesulfonate and benzenesulfonate were recovered from the water-soluble products.

Sulfonation of Di- and Trihalobenzenes. Considering the availability of the polyhalogenated benzenes their sulfonation reactions have been little investigated. The work done has been confined almost entirely to a few chloro and bromo compounds.

Sulfonation of *o*-dichlorobenzene at room temperature[177] or 210°[178] with oleum gives only the 4-sulfonic acid. The use of 7% oleum at 100° has also been recommended[179] for the preparation of this compound. If 2% or 10% of mercury is present as a catalyst the yields of 3-sulfonic acid are 16% and 26% respectively. This formation of an *ortho* isomer does not occur [180] except in the presence of a mercury catalyst. Chlorosulfonic acid yields the sulfone unless a solvent is used.[157b] *o*-Dichlorobenzene sulfonates more readily than the *para* isomer and a suggested method of separation [181] of the two compounds is based upon this difference in reactivity.

m-Dichlorobenzene has been sulfonated to the 4-sulfonic acid by oleum of varying composition.[178,179] Heating 30 g. of the dichlorobenzene with 70 ml. of 45% oleum at 140–150° for 5 hours gives the 4,6-disulfonic acid.[182] The corresponding disulfonyl chloride had previously [183] been prepared from resorcinoldisulfonic acid by heating with phosphorus pentachloride.

p-Dichlorobenzene has been converted to the monosulfonation product with sulfur trioxide [184] or 10% oleum.[179,185] Where oleum was used 24 hours' shaking was necessary to complete the reaction at room temperature. By heating *p*-dichlorobenzene at 150° for 1 hour with excess chlorosulfonic acid [186] an 85% yield of the sulfonyl chloride results; heating at 140° for 48 hours gives a mixture [187] of 2,5-dichlorobenzene-1,3-disulfonyl chloride and the isomeric 1,4-compound in which the former predominates.

Sulfonation of *o*-dibromobenzene in the absence of a catalyst gives only the 4-sulfonic acid while in the presence of 10% mercury a 24% yield of the 3-isomer was noted.[180] *p*-Dibromobenzene has been sulfonated with oleum under various conditions.[188] Apparently the *meta* compound has not been investigated in this connection. All three isomers give the sulfonyl chlorides with chlorosulfonic acid.[157b]

Various attempts to sulfonate *p*-diiodobenzene have given unsatisfactory results.[189] The maximum amount of the sulfonic acid was obtained by the use of sulfur trioxide, but at best no more than a 10% yield was isolated. Polyiodination products were always obtained. Chlorosulfonic acid at 50° gives 2,3,5,6-tetrachloro-1,4-diiodobenzene.[157b]

Of the mixed dihalobenzenes, apparently only *p*-chlorobromobenzene has been studied.[190] This gives with oleum a mixture of the two sulfonic acids in about equal [191] amounts. With chlorosulfonic acid the chief product is 2-bromo-5-chlorobenzenesulfonyl chloride.[157b]

1,3,5-Trichlorobenzene with excess chlorosulfonic acid gives the sulfonyl chloride while 72% oleum at 100° for 56 hours gives the disulfonic acid.[182] The corresponding tribromo compound has been monosulfonated,[192,193] and 1,2,4-tribromobenzene [194] gives the anhydride of an acid of unknown structure. Treating 1,2,3,5-tetrabromobenzene with oleum at 100° for fourteen days yields a monosulfonic acid.[193] Whether or not the bromines occupied their original positions was undetermined.

Sulfonation of Alkylhalobenzenes

The compounds formed in the sulfonation of benzene derivatives containing both alkyl and halogen groups are primarily of interest in determining the relative directive influence of these groups. It has already been pointed out that for the homologs of benzene substitution is predominantly *para* to the alkyl group but that *ortho* compounds are frequently present in reaction products; on the other hand, sulfonation of the halobenzenes occurs only in the *para* position. This difference in directive influence likewise manifests itself in the sulfonation of compounds containing both kinds of groups. In general the *para* directive influence of a halogen is greater than that of a methyl group, whereas for an *ortho* position the reverse is true. Thus 2-chlorotoluene forms only the 5-sulfonic acid while 4-chlorotoluene gives a mixture of the two possible isomers in which the 2-sulfonic acid predominates. The same generalization applies to more complex cases; sulfonation of 1,3-dimethyl-5-chlorobenzene and 1,3-dimethyl-4,6-dichlorobenzene gives only the 2-isomer (see Table III). Another interesting point is that the combined directing influence of an *ortho* and a *para* halogen is apparently less than for two methyl groups similarly placed. Thus 2,6-dichloro-1,3-dimethylbenzene sulfonates only in the 4-position. This generalization, however, rests upon less data than the preceding one.

There is no evidence regarding the directive influence of fluorine as compared with alkyl groups so far as sulfonation reactions are concerned, and only a little in the case of iodine. Likewise the relative influence of different alkyl groups in contrast with halogens is practically unknown.

Many of the sulfonic acids derived from the alkylhalobenzenes are unfortunately of unknown structure; such, for example, are the compounds derived from the fifteen dihalotoluenes.[195,196] In Table III which summarizes the results obtained in many sulfonation reactions of alkylhalobenzenes the sulfonic acids of undetermined structure have been assigned the most probable formulas, the positions thus assigned being followed by a question mark.

In a number of reactions sulfuric acid brings about a shift or elimination of halogen. Thus 4,6-diiodo-1-3-dimethylbenzene is sulfonated to the 2,4-diiodo-6-sulfonic acid, and 4-iodo-1,3-dimethylbenzene gives,

TABLE III

A. MONOSULFONIC ACIDS

Compound Sulfonated	Reagent* and Reference	Reaction Data	Position Sulfo Group	Remarks
Toluene derivatives				
2-Chloro-	*B*[1]	....	5	....
	A,[2] 100%, 3 parts	60°, 10 min.	5	....
3-Chloro-	*A*,[2] 100%, 3 parts	70°	6(?)	....
4-Chloro-	*B*[1]	....	2 and 3	....
	A,[2, 3] 100%, 3 parts	100°, 40 min.	2 and 3	86% of 2-
2-Bromo-	*B*[4]	....	5 and 6	6- in small amount
3-Bromo-	*B*[5]	Dissolves easily	6	....
4-Bromo-	*B*[6]	Warm	2 and 3	2- mostly
2-Iodo-	SO_3[7b]	Cold, then hot	5(?)	Also diiodo-compounds
	A,[7c] 1 part	4 hrs., 100°	5(?)	....
4-Iodo-	SO_3[7a]	$CHCl_3$ sol.	2 and 3	....
2,4-Dichloro-	*B*[8, 9]	Dissolves easily	5(?)	....
2,3-Dichloro-	*B*,[9] 3 parts	Heat	5(?)	....
2,5-Dichloro-	*B*,[9, 10] 10%	100°	4	....
2,6-Dichloro-	*B*[9]	....	3(?)	....
3,4-Dichloro-	*B*,[9, 11] 5%	....	6(?)	*A* does not react
3,5-Dichloro-	*B*[9]	....	2(?)	....
2,3-Dibromo-	*B*[12]	....	6(?)	....
2,4-Dibromo-	*B*[12]	....	5(?)	....
2,5-Dibromo-	*B*[12]	....	4(?)	....
2,6-Dibromo-	*B*[12]	....	3(?)	....
3,4-Dibromo-	*B*[12]	....	6(?)	....
3,5-Dibromo-	*B*[12]	....	2(?)	....
2-Bromo-3-chloro-	*B*[13]	100°, 15 min.	6(?)	....
2-Bromo-4-chloro-	*B*[13]	....	5(?)	....
2-Bromo-5-chloro-	*B*[13]	....	4(?)	....
2-Bromo-6-chloro-	*B*[13]	....	3 and 5(?)	One reported
3-Bromo-2-chloro-	*B*[13]	....	6(?)	....
3-Bromo-4-chloro-	*B*[13]	....	6(?)	....
3-Bromo-5-chloro-	*B*[13]	....	6(?)	....
3-Bromo-6-chloro-	*B*[13]	....	4(?)	....

* See p. 222 for meaning of *A*, *B*, and *C*.

TABLE III (*Continued*)

Compound Sulfonated	Reagent and Reference	Reaction Data	Position Sulfo Group	Remarks
4-Bromo-2-chloro-	*B*[13]	....	5(?)	....
4-Bromo-3-chloro-	*B*[13]	80°	6(?)	....
2,3,4-Trichloro-	*B*[14]	80°	5 and 6	Structures undetermined
3,4,5-Trichloro-	*B*[15]	70–80°	2	....
Benzene derivatives				
2-Bromo-1-ethyl-	*B*[16]	Reflux	5	....
4-Bromo-1-ethyl-	*B*[16]	Reflux	2	....
3-Chloro-1,2-dimethyl-	*B*[17]	....	6 and 4	Mostly 6
4-Chloro-1,2-dimethyl-	*B*[17]	....	5	....
3-Bromo-1,2-dimethyl-	*B*[18]	....	6 and 4(?)	Mostly 6
4-Bromo-1,2-dimethyl-	*B*[19]	....	5	....
4,5-Dibromo-1,2-dimethyl-	*B*,[20] 15%	75°	3	....
4-Chloro-1,3-dimethyl-	*B*[21]	....	6	....
5-Chloro-1,3-dimethyl-	*B*,[22] 6%	....	2	....
4-Bromo-1,3-dimethyl-	*B*[23]	Cold	6	....
4-Iodo-1,3-dimethyl-	*A*[24]	4–6 weeks	6	Diiodo-*m*-xylene also
4,6-Dichloro-1,3-dimethyl-	*C*[25]	....	2	....
4,6-Dibromo-1,3-dimethyl-	*B*[26]	70–80°	2	....
2,4-Dichloro-1,3-dimethyl-	*C*[25]	....	6	....
2,4-Dibromo-1,3-dimethyl-	*C*[27]	....	6	....
4,6-Diiodo-1,3-dimethyl-	*B*[28]	25°, 6 days	4	Iodines to 2,4-
2-Chloro-1,4-dimethyl-	*B*[29]	....	5	....
2,3-Dichloro-1,4-dimethyl-	*A*[47]	Reacts readily	5	....
2,6-Dichloro-1,4-dimethyl-	*A*[47]	Reacts readily	3	....
2,5-Dichloro-1,4-dimethyl-	*B*[47]	100°	3	....
2,5-Dibromo-1,4-dimethyl-	*B*,[30] 20%	80–85°	3	....
2(?)-Chloro-1-methyl-4-ethyl-	*A*[31]	130°	5(?)	....
2-Bromo-1-methyl-4-ethyl-	*A*[31]	130°	5(?)	....
5-Fluoro-1,2,4-trimethyl-	*A* or *B*[32]	....	6(?)	....
6-Bromo-1,2,4-trimethyl-	*B*[33]	....	3	....
3-Bromo-1,2,4-trimethyl-	*A* or *C*[34]	100°	5	Anomalous result
5-Bromo-1,2,4-trimethyl-	*B*[33, 34b]	....	6	Rearranges upon standing
5-Iodo-1,2,4-trimethyl-	*A* or *B*[46]	Long standing	6(?)	Also rearranges

TABLE III (*Continued*)

Compound Sulfonated	Reagent and Reference	Reaction Data	Position Sulfo Group	Remarks
5,6-Dibromo-1,2,4-trimethyl-	*C*[33]	....	3	Also rearranges
6(?)-Chloro-5-fluoro-1,2,4-trimethyl-	*C*[32]	....	3 or 6(?)	Cl lost
6(?)-Bromo-5-fluoro-1,2,4-trimethyl-	*C*[32]	....	3 or 6(?)	Br lost
2-Bromo-1,3,5-trimethyl-	*B*[35]	....	4	Also dibromomesitylene
2-Iodo-1,3,5-trimethyl-	SO_3[35b]	....	5	Also other products
2-Chloro-1-methyl-4-isopropyl	*B*,[36] 20%	....	5(?)	....
3-Chloro-1-methyl-4-isopropyl-	*C*[37]	....	6	....
2-Bromo-1-methyl-4-isopropyl-	*C*[38]	Equal weights	5	Also SO_2Cl comp.
	B[39]	....	5	Second isomer in traces
2-Bromo-1,3-dimethyl-5-ethyl-	*C*[40]	....	4	....
3-Chloro-1,2,4,5-tetramethyl-	*A*[41]	60°	......	See text, p. 222

B. DISULFONIC ACIDS

2-Chlorotoluene-4-sulfonic acid	*B*,[42] 35%	150°	6 and 5	Mostly 6
2-Chlorotoluene-5-sulfonic acid	*B*,[42] 20%	150°	3	....
4-Chlorotoluene-2-sulfonic acid	*B*,[43] 20%	150°	6 and 5	....
4-Chlorotoluene-3-sulfonic acid	*B*[43]	150°	5 and 6	....
4-Bromotoluene	*B*[44]	....	2,6-(?)	Only one acid reported
4-Chloro-1,3-dimethylbenzene	$H_2S_2O_7$[45]	Heat	2,6-	....

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[1] Hübner and Majert, *Ber.*, **6**, 790, 1692 (1873).

[2] Wynne, *J. Chem. Soc.*, **61**, 1073 (1892).

[3] (*a*) Vogt and Henninger, *Ann.*, **166**, 363 (1872). (*b*) Wynne and Bruce, *J. Chem. Soc.*, **73**, 731, 775 (1898).

[4] (*a*) Hübner and Post, *Ann.*, **166**, 34 (1873). (*b*) Miller, *J. Chem. Soc.*, **61**, 1029 (1892).

[5] Hübner and Grete, *Ber.*, **6**, 801 (1873); **7**, 795 (1874); Grete, *Ann.*, **177**, 233 (1875); Wroblewski, *Z. Chem.*, **6** (1871); *Ber.*, **7**, 1063 (1874); *Ann.*, **162**, 166 (1873).

[6] Hübner, Retschy, Hässelbarth, and Post, *Ann.*, **168**, 6, 15 (1873); Jennsen, *Ann.*, **172**, 238 (1874); Pechmann, *Ann.*, **173**, 208 (1874); v. Schäfer, *Ann.*, **174**, 357 (1874); Kornatzki, *Ann.*, **221**, 191 (1883).

[7] (*a*) Hübner and Glassner, *Ber.*, 8, 561 (1875). (*b*) Mabery and Palmer, *Am. Chem. J.*, **6**, 170 (1884). (*c*) Neumann, *Ann.*, **241**, 59 (1887).

[8] Seelig, *Ann.*, **227**, 159, 166 (1887).

[9] Wynne and Greevee, *Chem. News*, **72**, 58 (1895); Cohen and Dakin, *J. Chem. Soc.*, **79**, 1129 (1901).

[10] Wynne, *ibid.*, **61**, 1050 (1892).
[11] Wynne, *ibid.*, **61**, 1060 (1892).
[12] Cohen and Dutt, *ibid.*, **105**, 502 (1914).
[13] Cohen and Smithells, *ibid.*, **106**, 1909 (1914).
[14] Seelig, *Ann.*, **237**, 136 (1887).
[15] Wynne, *J. Chem. Soc.*, **61**, 1066 (1892).
[16] Sempotowski, *Ber.*, **22**, 2668 (1889); Moody, *Chem. News*, **71**, 197 (1895).
[17] Krüger, *Ber.*, **18**, 1756 (1885); Claus and Bayer, *Ann.*, **274**, 307 (1893).
[18] Stallard, *J. Chem. Soc.*, **89**, 809 (1906).
[19] Jacobsen, *Ber.*, **17**, 2373 (1884).
[20] Moody, *Chem. News*, **67**, 34 (1893).
[21] Gundelach, *Bull. soc. chim.*, [2] **28**, 343 (1877); Vogt, *ibid.*, [2] **12**, 221 (1869); Jacobsen, *Ber.*, **18**, 1762 (1885).
[22] Klages and Knoevenagel, *Ber.*, **27**, 3025 (1894); Klages, *Ber.*, **29**, 310 (1896).
[23] Weinberg, *Ber.*, **11**, 1063 (1878).
[24] Hammerrich, *Ber.*, **23**, 1635 (1890); Bauch, *Ber.*, **23**, 3118 (1890).
[25] Koch, *Ber.*, **23**, 2319 (1890).
[26] Jacobsen and Weinberg, *Ber.*, **11**, 1534 (1878).
[27] Jacobsen, *Ber.*, **21**, 2825 (1888).
[28] Töhl and Bauch, *Ber.*, **26**, 1107 (1893).
[29] Kluge, *Ber.*, **18**, 2099 (1885).
[30] Moody and Nicholson, *J. Chem. Soc.*, **57**, 976 (1890).
[31] Defren, *Ber.*, **28**, 2652 (1895).
[32] Töhl and Miller, *Ber.*, **26**, 1109 (1893).
[33] Jacobsen, *Ber.*, **19**, 1221 (1886).
[34] (*a*) Jacobsen, *Ber.*, **21**, 2822 (1888). (*b*) Kelbe and Pathe, *Ber.*, **19**, 1551 (1886).
[35] (*a*) Rose, *Ann.*, **164**, 63 (1872). (*b*) Töhl and Eckel, *Ber.*, **26**, 1102 (1893).
[36] Jünger and Klages, *Ber.*, **29**, 315 (1896); Klages and Kraith, *Ber.*, **32**, 2555 (1899).
[37] Carrara, *Gazz. chim. ital.*, **19**, 173, 502 (1889).
[38] Paterno and Canzoneri, *ibid.*, **11**, 126 (1881).
[39] Remsen and Day, *Am. Chem. J.*, **5**, 151 (1883); Kelbe and Koschnitzky, *Ber.*, **19**, 1732 (1886); Claus and Christ, *Ber.*, **19**, 2163 (1886); Dinesmann, German pat., 125,097, *Chem. Zentr.*, II, 1030 (1901).
[40] Töhl and Geyger, *Ber.*, **25**, 1536 (1892).
[41] Töhl, *Ber.*, **25**, 2760 (1892).
[42] Wynne and Bruce, *J. Chem. Soc.*, **73**, 737, 775 (1898).
[43] Wynne and Bruce, *ibid.*, **73**, 766 (1898).
[44] Kornatzki, *Ann.*, **221**, 192 (1883).
[45] Wischen, *Ber.*, **23**, 3117 (1890).
[46] Kürzel, *Ber.*, **22**, 1586 (1889).
[47] Wahl, *Compt. rend.*, **200**, 936 (1935).

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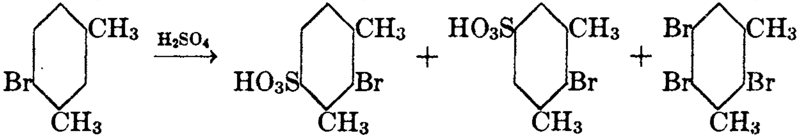
besides the 6-sulfonic acid, some 4,6-diiodo-1,3-dimethylbenzene. 5-Bromo-1,2,4-trimethylbenzene upon standing for four weeks with cold oleum [107] gives the several products indicated.



In addition there also is undoubtedly formed some of the unbrominated sulfonic acid. Sulfonation of iodo- and bromomesitylene gives similarly the dihalomesitylenes as by-products. Sulfonation of diiodomesitylene [108] produces some iodomesitylenesulfonic acid. The chlorine and bromine removed in the sulfonation of the x-halo-5-fluoro-1,2,4-trimethylbenzenes[199] were apparently not accounted for in the reaction products. 3-Chloro-1,2,4,5-tetramethylbenzene undergoes a typical Jacobsen rearrangement with sulfuric acid[200] at 60° while with the corresponding bromine compound it is the bromine that migrates giving dibromodurene[147, 201a,c] and the rearrangement products of durenesulfonic acid.

There should also be mentioned an investigation of the sulfonation of benzal chloride and benzotrichloride. With sulfur trioxide[201b] the former yields 10% *ortho,* 60% *para* and 30% *meta* sulfonic acids while the latter gives only the *meta* compound. Benzotrifluoride also probably gives the *meta* sulfonic acid.[201d]

In Table III, *A* is concentrated sulfuric acid. Where the percentage of acid differs from this or is accurately known it is given as *A*, 100%, etc.; *B* refers to oleum, the percentage indicating the sulfur trioxide content; *C* refers to chlorosulfonic acid. The reference numbers correspond to those in the list at the end of the table (see pp. 220–221).

The sulfonation of the 1- and 2-chlorotetralins[201e] is logically described here. The 1-chloro compound is converted into the 4-sulfonic acid whereas the 2-isomer sulfonates in the 3- position. The chlorides and amides of the acids were prepared.

SULFONATION OF NITRO COMPOUNDS

Sulfonation of the nitro derivatives of benzene and its homologs is a relatively unimportant method for the preparation of nitrosulfonic acids, because the nitration of a sulfonic acid occurs more easily than the sulfonation of a nitro compound. Where nitration gives a mixture of isomers while sulfonation yields chiefly one compound the latter method of preparation is, however, of some value.

Sulfonation of nitrobenzene with oleum[202] has been performed at various temperatures up to 150–160°. At a temperature of 60–90° not more than 2–3% of the reaction product is *p*-nitrobenzenesulfonic acid,[84, 203] the remainder being the *meta* isomer. No trace of the *ortho* compound could be found although some of the earlier[204] investigators had believed it to be present. These results are in contrast with those obtained in the nitration of benzenesulfonic acid[203, 205] in which all three isomers result, the relative amounts varying with the reaction conditions. By the addition of 5% of mercury as a catalyst in the sulfonation of nitrobenzene at 90° there are formed 75% of the *meta* and 25% of the *para* sulfonic acids.[84] If *o*-nitrophenylmercuric chloride is used instead of nitrobenzene the products depend upon the type of sulfonating agent. With 92% sulfuric acid 95% of the *meta* and 5% of the *para* isomers result while with 20% oleum 94% of the *ortho* and 6% of the *meta* compounds are formed. These results may be explained by two reactions undergone by aromatic mercury compounds.

$$\mathrm{ArHgCl} + \mathrm{H_2SO_4} \rightarrow \mathrm{ArH} + \mathrm{ClHgHSO_4}$$

$$\mathrm{ArHgCl} + \mathrm{SO_3} \rightarrow \mathrm{ArSO_3HgCl}$$

In the first equation the mercury salt obtained by the action of the sulfuric acid exerts little catalytic action, the *meta* and *para* sulfonic acids resulting in normal amounts. For a mercury catalyst to change the course of a reaction markedly it must be capable of mercurating the compound and there must be sulfur trioxide present in the reaction mixture.

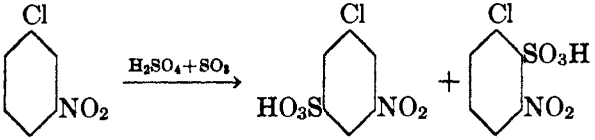
Heating nitrobenzene with two molecular equivalents of chlorosulfonic acid has been given [206] as a method for preparing *m*-nitrobenzenesulfonyl chloride, but in more recent [87] work chloranil was reported as the only product. Possibly a difference in the temperatures employed accounted for the different results. This reaction [207] and also the one with oleum [208] lead to violent decomposition with evolution of sulfur dioxide and formation of carbonaceous matter if the reaction mixtures are heated to a high temperature. With chlorosulfonic acid this may begin after heating at 150° for several hours.

Sulfonation of *m*-dinitrobenzene with oleum occurs only in the presence of a mercury catalyst.[209] At 150–160° a 27% yield of the *sym*-dinitrobenzenesulfonic acid is obtained.

Sulfonation of *o*-nitrotoluene with oleum has been reported [210] to give two sulfonic acids, but other investigators [211] were able to isolate only the *para* isomer. The sulfonation of *m*-nitrotoluene [212] yields only the 3-nitro-5-sulfonic acid. One or more isomers of this compound would be expected in this reaction. The behavior of *p*-nitrotoluene toward sulfonating agents has been studied in more detail. Oleum under various conditions [211b, 213] gives the *o*-sulfonic acid. The reaction occurs at a somewhat lower temperature (120°) than for nitrobenzene. A study of the kinetics [214] of the reaction with various reagents emphasized the necessity for the presence of sulfur trioxide in the sulfonating mixture. The constants for an apparently monomolecular reaction (large excess of sulfuric acid) were 0.003, 0.0004, and 0.000005 for 24% oleum, 100% sulfuric, and 99.40% sulfuric acid respectively. By heating *p*-nitrotoluene with an excess of chlorosulfonic acid [206, 215] first at 70–80° then at 120° the *o*-sulfonyl chloride is obtained.

Ortho and *para* nitroethylbenzenes each give a single sulfonic acid when treated with oleum.[216] The structures of these compounds are undoubtedly analogous to those of the toluene derivatives. 4-Nitro-1,3-dimethylbenzene with oleum [217] gives the 6-sulfonic acid. Heating with two molecular equivalents of chlorosulfonic acid [206, 217b] produces the corresponding sulfonyl chloride. 5-Nitro-1, 4-dimethylbenzene with the same reagent [91d] is converted into a mixture of the 2- and 3-sulfonyl chlorides. The sulfonic acids derived from the nitrotetralins may be noted here. 1-Nitrotetralin with sulfuric acid [100c] yields the 3-sulfonic acid, and the 2-nitro compound gives the 4-sulfonic acid.

Only a few halogen derivatives of nitrobenzene have been sulfonated and apparently no nitro compounds containing both halogen and alkyl groups have been investigated. *o*-Chloro-[218] and *o*-bromonitrobenzene [219] sulfonate only in the positions *para* to the halogens. *p*-Chloronitrobenzene with oleum [218, 220] gives 2-chloro-5-nitrobenzenesulfonic acid and with chlorosulfonic acid [87] at 160–170° yields the corresponding acid chloride. *p*-Bromonitrobenzene has also been sulfonated with oleum.[219, 221] *m*-Chloronitrobenzene [222] behaves unusually since in one of the sulfonic acids the sulfo group is *ortho* to both chloro and nitro groups.



2,3-Dichloro-5-nitrobenzenesulfonic acid has been mentioned as an intermediate in the preparation of the corresponding amine. It was obtained by the action of oleum [223] upon 3,4-dichloronitrobenzene.

SULFONATION OF ALDEHYDES AND KETONES

Here only the aldehydes and ketones containing one benzene ring will be considered. Benzophenone and other polynuclear compounds are discussed later.

Despite the ease with which aromatic aldehydes are oxidized no oxidation products have been reported from the action of sulfonating agents. Benzaldehyde is sulfonated by the action of two parts of oleum at 50° or below [224] or by sulfur trioxide,[225] substitution occurring in the *meta* position. 2-Chlorobenzaldehyde reacts with oleum at room temperature [226] while the 4-chloro compound is unaffected [227] at 85°. This difference is of value in separating the two isomers. Sulfonation occurs *para* to the chlorine. 2,6-Dichlorobenzaldehyde [228] sulfonates in the 3-position. Introduction of a sulfo group into 4-bromobenzaldehyde requires the heating of 7 g. with 50 g. of 18% oleum[229] at 150°; sulfonation occurs in the 3-position. It is claimed that 3-methylbenzaldehyde with 60% oleum[230] at 0° sulfonates in one of the positions *ortho* to the aldehyde group.

Apparently 3-hydroxybenzaldehyde has not been sulfonated but the anil has been converted into the 6-sulfonic acid by the action of oleum.[231] 4-Hydroxybenzaldehyde gives the 3-sulfonic acid by warming to 65° with the same reagent.[232] At 50° 2-hydroxy-5-methylbenzaldehyde also gives the 3-sulfonic acid.

Of the ketones only acetophenone has received any appreciable study. With four parts of pyrosulfuric acid[233a] at 100° for 30 min. it is monosulfonated, mostly in the *meta* position;[233b] if the temperature is not kept low while the acetophenone is dissolved in the acid, benzoic acid and benzenesulfonic acid are formed. This also occurs with sulfuric acid. Heating acetophenone with ten parts of chlorosulfonic acid[234] at 110° for an hour gives the 2,ω-disulfonyl chloride.[233b] Acetophenone-4-sulfonic acid with the same treatment gives an isomeric disulfonyl chloride, probably the 4,ω- compound.

Methyl benzyl ketone with pyrosulfuric acid[233] yields a sulfonic acid of unknown structure, while with sulfuric acid phenylmethanesulfonic acid and acetic acid are the products.

$$C_6H_5CH_2COCH_3 + H_2SO_4 \rightarrow C_6H_5CH_2SO_3H + CH_3COOH$$

An unstable disulfonic acid is formed by the action of sulfuric acid upon dichloromethyl 2,3,4-trihydroxyphenyl ketone[235] at room temperature. It has been found that oleum[236] sulfonates hexachlorocyclohexyl phenyl ketone to a monosulfonic acid.

SULFONATION OF CARBOXYLIC ACIDS

A carboxyl group attached to a benzene ring influences sulfonation reactions in at least three ways: (1) As with other *meta* orienting groups the reactivity of the compound is somewhat reduced. (2) Sulfonation is facilitated by the solubility[237] of the carboxylic acid in the sulfonating agent. (3) The formation of a mixed anhydride or an addition compound may occur as a first step in the reaction. For acids in which the carboxyl group is separated from the benzene ring by a saturated side chain the *meta* directive influence and the effect on the reactivity[237] are lost. However, for cinnamic acid the *meta* isomer is still formed in appreciable amount. The side chain is not affected in this reaction.

A considerable number of carboxylic acids have been sulfonated but only for benzoic acid has the reaction been investigated quantitatively.

Sulfonation of Benzoic Acid. Although the methods and results of various investigators differ as to details, monosulfonation of benzoic acid has been found to give a product containing at least 80% of the *m*-sulfobenzoic acid, the remainder being chiefly the *para* isomer. In a series of sulfonations [238] in which 93% and 100% sulfuric acid and 19% oleum [239] were employed at various temperatures ranging from 140° to 209°, and for reaction times varying from 2 to 48 hours the reaction products contained from 80.7 to 96.4% of the *meta* isomer. Only for the longer periods at a high temperature did this fall below 90%. The decrease was because of the slow conversion of the *meta* into the *para* isomer which amounted to as much as 15% of the *meta* compound. It was found that neither silver nor potassium sulfate had any influence upon the composition of the reaction product.

The catalytic influence of mercuric sulfate upon the reaction has been studied by several investigators with conflicting results. It was first [240] reported that the rate of sulfonation was increased appreciably and that the *ortho* isomer was produced in 5–7.5% yields when mercuric sulfate was present while in its absence only the *meta* and *para* compounds were formed. Maarse [238] came to a similar conclusion except that the amount of *ortho* isomer was reported as 0.7%. More recently Reese [241] has shown that with sulfuric acid the amount of *ortho* isomer is decreased rather than increased by adding mercuric sulfate because it catalyzes the conversion of the *ortho* into the *meta* isomer. However, when 10% oleum [84] is used as the sulfonating agent, the presence of 5% mercury results in a reaction product containing 5% *ortho,* 69% *meta,* and 26% *para* isomers. By starting with *o*-carboxyphenylmercuric chloride a 97% yield of the *o*-sulfonic acid is realized. These varying conclusions are at least partly due to the difficulties encountered in analyzing the reaction products. Maarse [238] made a careful investigation of the system formed by the chlorides obtained in treating the sulfobenzoic acids with phosphorus pentachloride and used the results in analyzing the mixtures he obtained. The interpretation of the analyses was somewhat difficult due to the existence of the *o*-dichloride in two forms and the possible presence of compounds containing two sulfo groups. Also under some conditions a small percentage of the benzoic acid is converted into benzenesulfonic acid. Reese fused the reaction mixtures with alkali and determined the amount of salicyclic acid present by chloroform extraction of the phenolic compounds. This method, however, does not distinguish between the *meta* and *para* isomers.

It was at one time [242] reported that iodine exerts a catalytic influence in the sulfonation of benzoic acid but other [248] investigators found this conclusion to be erroneous, the product obtained with sulfuric acid or oleum being the same whether iodine was present or not. In these reactions the *ortho* isomer was shown to be present in small amounts by conversion into phenolsulfonphthalein.

The mechanism of the sulfonation reaction of carboxylic acids is complex. A study [241] of the rate of disappearance for benzoic acid compared with the rate of formation of the sulfo acids indicated that some intermediate product, possibly benzoyl hydrogen sulfate, is the first step in the reaction. The comparatively large percentages of *o*-sulfobenzoic acid present in the reaction product obtained for short reaction times indicated that this also might be an intermediate. Separate experiments showed that *o*-sulfobenzoic acid did rearrange under the conditions prevailing in the reaction mixture. The table of results is reproduced below.

TABLE IV

SULFONATION OF BENZOIC ACID AT 200°

Time, Hours	Acid Reacted, %	Sulfonic Acids Recovered, %	*ortho* Substitution	
			Without Hg	With Hg
3	99.1	98.3	6.3	2.3
1	95.5	93.3	5.8	3.8
0.33	81.0	75.0	14.3	7.3
0.08	35.9	11.6	....	...

It should be pointed out, however, that the evidence does not prove that all the *m*-sulfobenzoic acid results from rearrangement of the *ortho* isomer.

In addition to the procedures already given *m*-sulfobenzoic acid has been obtained by the action of sulfur trioxide [244] upon benzoic acid and from benzoyl chloride and sulfuric acid [245] or silver sulfate.[246] Dioxane sulfotrioxide [22c] at room temperature gives benzoyl hydrogen sulfate. Chlorosulfonic acid yields the 3-sulfonyl chloride.[248c]

$$C_6H_5COOH + O(CH_2CH_2)_2OSO_3 \rightarrow C_6H_5COOSO_3H + O(CH_2CH_2)_2O$$

The hydrogen chloride evolved in the reaction of 95% sulfuric acid with benzoyl chloride is not produced by formation of benzoyl sulfate as 100% acid gives an addition product without further reaction.[247] Heating benzoic acid to 250° with a mixture of oleum and phosphorus pentoxide [248a] or with 70% oleum [248b] in a closed tube gives 3,5-disulfobenzoic acid. The action of 30% oleum gives good results at atmospheric pressure.[249] *m*-Sulfobenzamide has been obtained by the action of sulfur trioxide [250] upon benzonitrile. Hippuric acid with the same reagent yields the *m*-sulfonic acid.[251]

Sulfonation of Halobenzoic Acids. Several halobenzoic acids have been sulfonated. *p*-Chlorobenzoic acid with pyrosulfuric acid [252] at 120–130° gives 3-sulfo-4-chlorobenzoic acid. The structure of the acid obtained by the action of sulfur trioxide upon 3-chlorobenzoic acid was not determined,[253] but it probably has the symmetrical configuration since this is true for the compound formed from 3-bromobenzoic acid.[254,255] Sulfonation of 2-bromobenzoic acid [256] with oleum produces the 5-sulfonic acid as might be expected from the strong *para*-directing influence of the bromine. Quite unexpectedly, *p*-bromobenzoic acid has been reported [255,257] to give a mixture of both possible sulfonic acids. The 3-sulfo-4-bromobenzoic acid gives an insoluble barium salt which made the separation of the two isomers easy of accomplishment. The 2-sulfonic acid was not found by Van Dorssen,[256b] however.

Sulfonation of Alkylbenzoic Acids. *Ortho* [239e,258,259] and *para* [260] toluic acids each yield only one sulfonation product, substitution occurring *para* to the methyl in the first acid and *ortho* in the other. *m*-Toluic acid,[261] however, when heated with sulfuric acid at 180° gives three isomeric sulfo compounds; 3-sulfo-5-methylbenzoic acid is the principal product but the 2- and 4-compounds are also formed. *o*-Toluic acid may be converted into 3,5-disulfo-2-methylbenzoic acid by heating with pyrosulfuric acid.[258]

3,5-Dimethylbenzoic acid when kept in contact with sulfur trioxide [262] for 48 hours is converted into a mixture of the two possible monosulfonic acids. The one having adjacent acid groups forms a calcium salt that is only slightly soluble in water.

p-*n*-Propyl and *p*-isopropylbenzoic acids have been converted into the *m*-sulfonic acids by the action of sulfur trioxide.[263a]

By treating phenylacetic acid with chlorosulfonic acid [186] it is possible to obtain a 35% yield of the *p*(?)-sulfonyl chloride. When heated with sulfuric acid [263b] at 80–95° a mixture of the 2- and 4-sulfonic acids results. The sodium salts of the 4-sulfo compound are less soluble than those of its isomer.

Hydrocinnamic acid with 20% oleum [239e] yields a sulfonic acid, probably the *para* compound. Oleum acts upon *p*-bromohydrocinnamic acid [264] in two ways, the products being 6-bromo-1-indanone and 3-sulfo-4-bromohydrocinnamic acid. The carboxyl group thus apparently reduces the *ortho* directive influence of the side chain considerably since with *p*-haloalkylbenzenes the *o*-sulfonic acid is the major product.

Sulfonation of Cinnamic Acid. The sulfonation of cinnamic acid with oleum has occasioned considerable interest [265] because of the somewhat unusual directive influence shown by the unsaturated side chain. It has been only comparatively recently [266] that the secondary product of the reaction has been conclusively demonstrated to be the *m*-sulfonic acid. From 50 g. of cinnamic acid and 150 g. of 18% oleum, 43–45 g. of barium *p*-sulfocinnamate and 17 g. of barium hydrogen *m*-sulfocinnamate are obtained. If any *ortho* compound is formed it amounts to considerably less than 1% of the total product. The structures of the two isomers are evident from their conversion to the corresponding hydroxybenzoic acids by fusion with alkali. The non-identity of the *m*-sulfonic acid with the *o*-isomer which were confused at first was shown by the synthesis of the former from *m*-sulfobenzaldehyde [267] by the Perkin reaction and the latter from *o*-bromocinnamic acid and sodium sulfite.[266] It has also been observed that oxidation of the sulfonamide obtained from the sulfonic acid formed in smaller amount does not give saccharin,[268] a product to be expected from the *ortho* sulfonamide. With chlorosulfonic acid [186] cinnamic acid apparently yields only the *p*-sulfonyl chloride.

Sulfonation of the Phthalic Acids. The sulfonation of a benzene nucleus to which are attached two *meta*-directing groups is extremely difficult. Heating phthalic acid with sulfur trioxide at 100–105° in a closed tube gives a small yield [269, 270] of the 4-sulfonic acid. Better results are obtained by the use of an autoclave and higher temperatures [271] or by passing sulfur trioxide into phthalic anhydride kept at 190–210° in an all-glass apparatus.[272] The reaction product obtained by heating a mixture of phthalic anhydride and 20–25% oleum [270] at 190–210° and passing in sulfur trioxide contains a small amount of the 3-sulfonic acid in addition to the 4-isomer.[230e] Various salts [273] of the two compounds have been studied in detail. In the presence of mercury salts [274] the sulfonation proceeds more readily and the 3-sulfonic acid becomes the chief product. At 200° with sulfur trioxide and mercuric sulfate [272] the 3,5-disulfonic acid is the reaction product. The structure was ascertained by conversion into 3,5-dichlorophthalic anhydride through heating with thionyl chloride to 180°.

Isophthalic acid has been changed into the symmetrical sulfo compound by treatment with sulfur trioxide [275] and by heating with oleum at 200° for 6 hours.[276] Satisfactory results are obtained in the case of terephthalic acid by heating the reaction mixture to 250–260° under pressure.[277]

SULFONATION OF PHENOLS AND THEIR DERIVATIVES

The ease with which phenols undergo sulfonation reactions may be caused not only by the directive influence of the hydroxyl group but also by the possibility of the formation of intermediate compounds which rapidly undergo rearrangement. Thus phenol at a low temperature with either sulfuric or chlorosulfonic acid gives a considerable amount of phenyl hydrogen sulfate, a compound that readily rearranges (see p. 47) to the *para* sulfonic acid.

$$C_6H_5OH + H_2SO_4 \rightarrow C_6H_5OSO_3H \rightarrow HO_3SC_6H_4OH$$

This does not demonstrate that the sulfonation of phenols always occurs through an ester intermediate, but it may play an important role. The ready solubility of phenols in sulfonating agents facilitates their sulfonation as with other oxygen compounds.

It has already been mentioned that a number of substituted phenols under the influence of oleum or chlorosulfonic acid are converted into sulfonylides. These result most frequently when substituents are present in the *ortho* or *para* position in the original phenol.

Sulfonation of Phenol. Heating phenol with slightly more than an equal weight of sulfuric acid [278] at 90–150° or treating it with a larger amount of this reagent at a lower temperature produces a mixture of the *o*- and *p*-sulfonic acids. The ratio in which the isomers are formed varies considerably with the temperature. Although some investigators [278a] have reported that at a low temperature the *ortho* isomer predominates, a careful quantitative [279] separation of the sulfonic acids made possible by the difference in solubility of their barium salts showed that even under the most favorable conditions (0–5°) not more than 40% of the *ortho* compound is formed, while at 100° this is reduced to about 10%. At 100° an 85% yield of barium *p*-phenolsulfonate was isolated. At 0° there is produced, in addition to the sulfonic acids, an appreciable amount of phenyl hydrogen sulfate. On the other hand, at a temperature of 160° or above some bis-(*p*-hydroxyphenyl) sulfone [279, 280] is formed unless an excess of sulfonating agent is used. The sulfone may be made the main product by heating 100 g. of phenol with 50 g. of 20% oleum [281] for 5 hours at 180–190°. It is accompanied by 4–5% of an isomer which is probably either the 2,4′- or the 2,2′-compound. This isomer with oleum at 90–100° gives phenol-2,4-disulfonic acid and at 180–190° a trisulfonic acid while the 4,4′-sulfone yields a disulfonic acid without undergoing hydrolysis. Monosulfonation of phenol has been carried out technically by the use of oleum with satisfactory results.[282]

Early investigators[278a,b] believed that the *ortho* sulfonic acid readily rearranged to the *para* isomer but since this has been shown to take place only under conditions where hydrolysis and resulfonation are possible it is likely that no direct rearrangement occurs.[283]

An investigation of the reagent[284] used in the colorimetric determination of nitrates which is prepared from phenol and sulfuric acid showed that the abnormal results sometimes obtained are caused by variation in the composition of the phenol-sulfuric acid mixture. Under the conditions of the analysis the monosulfonic acids give a green nitro compound whereas the nitro-2,4-disulfonic acid is yellow. After heating phenol with an excess of sulfuric acid at 100° for 5 hours neither of the monosulfonation products remains in the reaction mixture. Separation of a mixture containing *o*- and *p*-phenolsulfonic acids and the disulfonic acid is readily accomplished since barium phenol-2,4-disulfonate is only very slightly soluble in a solution of the other barium salts and barium phenol-*p*-sulfonate is so extremely soluble in water that the *ortho* compound can be completely removed before the *para* sulfonate separates from the solution.

An equivalent amount of chlorosulfonic acid at ordinary temperature[285] converts phenol into a mixture of the *o*- and *p*-sulfonic acids containing mostly the *para* isomer. At 15° in carbon bisulfide[286] phenyl hydrogen sulfate and the *p*-sulfonic acid are the only products. Slow addition of the chlorosulfonic acid or long standing of the reaction mixture increases the yield of the sulfonic acid. Under the conditions most favorable for ester formation the yield of the *p*-sulfonic acid amounted to only one-third of the phenol used. With fluorosulfonic acid in excess at ordinary temperatures[27a] a high yield of the *p*-sulfonyl fluoride is obtained.

Heating phenol with sulfamic acid[287] at 150° rapidly converts it into ammonium *p*-phenolsulfonate; at 100°, on the other hand, ammonium phenyl sulfate results. This is further evidence that a sulfonation reaction may occur in two stages. The addition product formed by pyridine and sulfur trioxide[288] behaves in an analogous manner.

$$C_6H_5OH + C_5H_5NSO_3 \xrightarrow{50^\circ} C_6H_5OSO_3NC_5H_5 \xrightarrow{150^\circ} C_5H_5NHO_3SC_6H_4OH$$

As already mentioned, disulfonation of phenol is readily effected by a large excess of sulfuric acid[284,289,290] at 100°. This has also been brought about by the use of equal amounts of oleum and sulfuric acid.[291] Through the action of one molecular equivalent of chlorosulfonic acid[269] at ordinary temperature upon potassium phenol-*p*-sulfonate the 2,4-disulfonic acid results, while treatment of phenol with an excess[292] of this reagent produces the 2,4-disulfonyl chloride. Heating with excess fluorosulfonic acid[27a] gives the disulfonyl fluoride.

Sulfonation of phenol with ten times its weight of 20% oleum at 120° gives over 80% of the 2,4,6-trisulfonic acid, the other product being the disulfo compound. Various other concentrations of oleum have been reported[293] as producing similar results at 100°. Heating phenol with excess chlorosulfonic acid[292] at 130–140° yields phenol-2,4,6-trisulfonyl chloride.

Sulfonation of Phenyl Alkyl Ethers. At ordinary temperatures treating anisole with sulfuric acid[294, 295] gives some of the *o*-sulfonic acid unless the ratio of acid to anisole is greater than four to one; in this event only the *para* compound and the 2,4-disulfonic acid result. Apparently the *para* isomer is the only one formed when the sulfonation is carried out in the presence of acetic acid and acetic anhydride.[296] By heating anisole with ten parts of sulfuric acid at 90° for 30 minutes only the 2,4-disulfonic acid results whereas with two parts of acid at 150–160° a trace of the 4-sulfonic acid was the only compound isolated. Possibly the absence of anisole-2,4-disulfonic acid in the product is caused by removal of the methyl group since a high yield of mixed sulfonic acids of unknown composition was obtained. If phenol-2,4-disulfonic acid were the chief product it would hardly have been noticed as the method of identifying the reaction products included a treatment with phosphorus pentachloride and conversion of the sulfonyl chlorides to the amides. This is of course not feasible for a sulfonic acid containing a phenolic group. This explanation is not entirely satisfactory, however, as heating bis-(*p*-methoxyphenyl) sulfone[297] with sulfuric acid at 160–180° produces *p*-methoxybenzenesulfonic acid rather than a demethylated compound. Oleum[298] converts anisole readily into the disulfonic acid. Fluorosulfonic acid has been reported[27a] to give a 22% yield of the 4-sulfonyl fluoride. Chlorosulfonic acid in chloroform acts in similar fashion.[299]

The principal compound obtained in sulfonating phenetole is likewise the *p*-sulfonic acid.[300] This was once claimed to be the only product but other investigators have found an isomeric compound to be present in small amount. This was first believed to be the *ortho* isomer,[300a] the sulfonamide having a melting point of 142°. It was shown a little later,[301] however, that the *o*-sulfonamide melted at 163°. An extensive study of this sulfonation under various conditions of temperature and reaction time[302] showed that the secondary reaction product usually amounted to 5–10% of the total sulfonic acids. The sulfonamide obtained had a melting point corresponding quite closely to that of the *m*-sulfonic acid. Since the formation of a *meta* compound seems unlikely, the supposed *m*-sulfonamide may have been a mixture of the *ortho* and *para* isomers, each of which melts considerably higher than the *meta*. If this is not the explanation, the ether oxygen has become *meta* directing because of salt formation with the sulfuric acid. Further investigation on this point would be welcome.

When equal quantities of phenetole and sulfuric acid are heated at 90° the maximum yield of *p*-sulfonic acid is produced in 30 minutes. Longer heating converts an increasing quantity of this into a disulfonic acid. Oleum[302] also gives the disulfonic acid readily at 85°. With fluorosulfonic acid[27a] the 4-sulfonyl fluoride is the reaction product. Similar reactions occur with chlorosulfonic acid and phenetole, *n*-propyl phenyl ether, and *n*-butyl phenyl ether in chloroform solution.[299]

High-molecular-weight esters of phenoxyacetic acid[303b] have been sulfonated to give sulfonic acids of foam-producing power. The corresponding amides, $C_6H_5OCH_2CONHR$, have also been converted into sulfonates.[303c]

Sulfonation of cetyl phenyl ether with concentrated acid at 70° produces the *p*-sulfonic acid. This was isolated from the reaction mixture by extraction with carbon tetrachloride. An aqueous solution of the sulfonic acid and its alkali salts have a strong emulsifying action.[303d]

When 3-cyano-1-phenoxypropane is allowed to stand with sulfuric acid for 6 hours,[303a] both sulfonation and amide formation occur.

$$C_6H_5OCH_2CH_2CH_2CN + H_2SO_4 \rightarrow HO_3SC_6H_4OCH_2CH_2CH_2CONH_2$$

Sulfonation of Phenyl Esters. The action of sulfur trioxide upon phenyl benzoate[304] produces a sulfonic acid which is probably the *para* compound, the sulfo group entering the phenol ring. Phenyl salicylate (salol) with sulfuric acid[278] undergoes hydrolysis and gives a high yield of phenol-*p*-sulfonic acid.

Sulfonation of the Cresols. A careful study of the rates[305] at which phenol and the cresols undergo sulfonation with 96% sulfuric acid at various temperatures revealed that the difference in the rates for *m*- and *p*-cresol was sufficient to be of practical value in separating these two compounds.[306] In Table V the sulfonation rate for phenol is taken as unity for each temperature.

Investigation of the sulfonic acids obtained from *o*-cresol has shown that at room temperature with sulfuric acid[307,308] a mixture of the *o*- and *p*-sulfo compounds results while at 100° the product is practically all the *para* isomer.[308,309] The two compounds may be separated by the difference in the solubilities of their barium salts. By heating *o*-cresol[307] at 100°, or bis-(4-hydroxy-3-methylphenyl) sul-

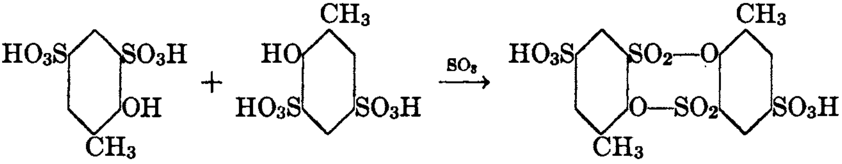
TABLE V

RELATIVE SULFONATION RATES

Compound	20°	40°	60°	80°
Phenol	1.00	1.00	1.00	1.00
o-Cresol	0.773	0.859	0.894	0.905
m-Cresol	1.395	1.362	1.118	0.399
p-Cresol	0.300	0.474	0.537	0.287

fone[310] at 160–170° with excess oleum the cresol-4,6-disulfonic acid is formed. However, if the *o*-cresol is treated with only one-half its weight of 8% oleum[310] at 160–180° for 3 hours under reflux,[311] a high yield of the aforementioned sulfone is obtained, a monosulfonic acid occurring as a by-product.

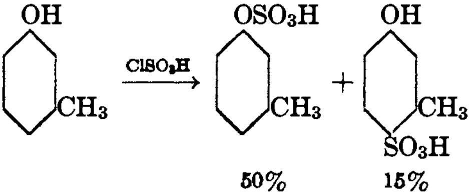
By heating 10 g. of *o*-cresol with 15 g. of 95% sulfuric acid at 100° for a few minutes and then with 135 g. of 25% oleum for several hours, the sulfonylide results.[312]

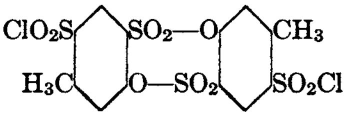


This compound and others of a similar type were readily purified by crystallization from dilute hydrochloric acid. The same product was obtained along with its disulfonyl chloride as an amorphous powder by the action of excess chlorosulfonic acid[313] at 140° upon *o*-cresol. The sodium salt is somewhat insoluble in water. The corresponding disulfonyl chloride is also formed by heating *o*-cresol with chlorosulfonic acid at 110°. At room temperature the cresol-4,6-disulfonyl chloride is obtained.[314, 315a] With fluorosulfonic acid *o*-cresol is converted into the 4-sulfonyl fluoride[27a] in an 8% yield; with more of the reagent at 80–90° a 15% yield of the sulfonylidedisulfonyl fluoride was isolated.[315b]

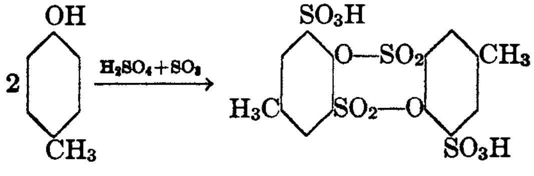
In the first investigations[316] of *m*-cresol only one sulfonic acid was isolated when the sulfonation was performed at 120° with sulfuric acid. The structure of this was indicated by its oxidation to *p*-toluquinone. At a higher temperature with excess acid di- and tri-sulfonic acids result. More recently[317] it has been shown that the 6-sulfonic acid is at 30–35° or 100° from 25 to 35% of the reaction product. This is present in much smaller amount when the reaction mixture is heated at 120°. In addition, at low temperatures an appreciable amount of *m*-tolyl hydrogen sulfate is also formed. *m*-Cresol gives no sulfonylide with oleum[312] thereby differing from the *ortho* and *para* isomers.

In carbon bisulfide at −15° an equivalent amount of chlorosulfonic acid gives the two compounds shown. None of the isomeric 6-sulfonic acid was detectable. By heating the reaction mixture at 100° the *m*-tolyl hydrogen sulfate was rapidly converted to the 4-sulfonic acid. In the absence of a solvent at room temperature a trace of *m*-tolyl sulfate[818] is formed along with the 4-sulfonic acid. With two or three molecular equivalents of chlorosulfonic acid[817] in carbon disulfide the 4,6-disulfonic acid was the only product isolated. At room temperature with a large excess of this reagent the 4,6-disulfonyl chloride was obtained. By heating the reaction mixture at 110° a sulfonylide resulted. The most probable structure is that of the accompanying formula. By first heating the mixture to 130–140° and pouring into water the *m*-cresoltrisulfonic acid is obtained, whereas if the reaction mixture is added to hydrochloric acid the trisulfonyl chloride precipitates. With fluorosulfonic acid at room temperature a sulfonyl fluoride[27a] results; after heating at 80–90° for 2 hours with excess reagent a disulfonyl fluoride is produced.[815b]

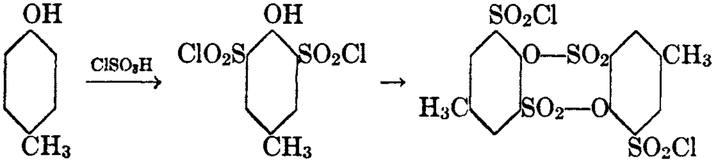




p-Cresol with an equal weight of sulfuric acid[809, 819a] or 6% oleum[819b] at 100° is converted into the 2-sulfonic acid. By the use of fifteen times its weight of 20% oleum[812, 819a, 820] a sulfonylide results in 87% yield. This crystallizes readily from hydrochloric acid. Its sodium and potassium salts are only slightly soluble in water. It is claimed[821] that high-temperature sulfonation also gives rise to a small amount of the 3-sulfonic acid. By the action of sulfuric acid upon a sulfone obtained from *p*-cresol, the cresol-2,6-disulfonic acid is formed.



One molecular equivalent of chlorosulfonic acid[286] at 15° in carbon disulfide yields a mixture of *p*-tolyl hydrogen sulfate and the *p*-cresol-*o*-sulfonic acid. As with other cresols, excess chlorosulfonic acid at ordinary temperatures[318] gives the disulfonyl chloride. Upon heating, the sulfonylidedisulfonyl chloride is produced. The action of fluorosulfonic acid is analogous[315b] to this except that it is possible to obtain



the monosulfonyl fluoride[27a] by performing the reaction in carbon disulfide at 20°.

Sulfonation of Other Alkylphenols. The action of chlorosulfonic acid at various temperatures upon five of the xylenols has been investigated in detail.[322] Sulfonylides are not formed when the sulfonyl chloride group is between the hydroxyl and methyl groups. Thus, only 2,3-dimethylphenol and 2,4-dimcthylphenol give appreciable yields of sulfonylides. Contrary to what might be expected from the directive influences of the methyl and hydroxyl groups, 3,4-dimethylphenol gives the 2,5-disulfonyl chloride and 2,5-dimethylphenol gives the 3,6-disulfonyl chloride. These structures were adopted because the sulfonic acids obtained from the hydrolysis of the disulfonyl chlorides coupled with diazotized *p*-nitraniline. It would seem that there must be some explanation for dye formation other than the supposed presence of an unoccupied position *ortho* to a hydroxyl, as the entrance of a sulfo group *meta* to both hydroxyl and methyl is very unlikely. The monosulfonyl chloride obtained from 2,4-dimethylphenol decomposed readily upon standing, and it was therefore suggested that it might be a chlorosulfonate, $(CH_3)_2C_6H_3OSO_2Cl$, instead of the sulfonyl chloride. Either of these compounds could be a precursor of the sulfonylide also obtained from this phenol. The sulfonation of a variety of higher alkylphenols prepared by condensing phenol with alcohols, chlorides, or olefins has been described in the patent literature.[323] The resulting sulfonic acids or their salts are useful as detergents or wetting agents.

The results reported for the sulfonation of other alkylphenols containing one or more alkyl groups are listed in Table VI. Here as in previous tables *A* represents sulfuric acid, *B*, oleum, and *C*, chlorosulfonic acid. The references for the table are given in a list at the end of the tabulation of results.

TABLE VI

SULFONATION OF ALKYLPHENOLS

Compound Sulfonated	Reagent and Reference	Reaction Data	Position of Sulfo Group
Phenol derivatives			
2-Ethyl-	$A^{1,2}$	100°	4-
3-Ethyl-	A^{2}	"Warm"	4- (?)
4-Ethyl-	$A^{2,3}$	....	2-
4-*n*-Propyl-	A^{4}	100°, 1 hr.	2-
4-*n*-Butyl-	A^{4}	100°, 1 hr.	2-
4-*n*-Amyl-	A^{4}	100°, 1 hr.	2-
4-*n*-Hexyl-	A^{4}	100°, 1 hr.	2-
4-*tert*-Butyl-	B^{5}	70–80°	2-
4-*tert*-Amyl-	A^{5}	70–80°	2-
3,4-Dimethyl-	A^{6}	....	6- (?)
2,4-Dimethyl-	$A^{6,7}$	....	3- and 6-
3,5-Dimethyl-	A or B^{8}	....	2-
2,5-Dimethyl-	A^{6}	Warm	4- (?)
2-Methyl-5-isopropyl-	A^{9}	Equal weights	4-
5-Methyl-1-isopropyl-	$A^{10,11}$	−5°	4- and 6-
	$A^{10,11,12}$	50–100°	4-
	$C^{11,13}$	....	4-
2,4,5-Trimethyl-	A^{14}	....	6- (?)
2,4,6-Trimethyl-	A^{15}	....	3-
Tetralin derivatives			
2-Tetralol	A^{16}	....	3-
1-Tetralol	A^{17}	Cold, 2 days	4-

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[1] Suida and Plohn, *Monatsh.*, **1**, 179 (1880).

[2] Sempotowski, *Ber.*, **22**, 2673 (1889).

[3] Fittig and Kiesow, *Ann.*, **156**, 254 (1870).

[4] Suter and Moffett, *J. Am. Chem. Soc.*, **54**, 2983 (1932).

[5] Liebmann, *Ber.*, **15**, 151 (1882); ANSCHÜTZ, *Ann.*, **415**, 83 (1918).

[6] Jacobsen, *Ber.*, **11**, 28 (1878).

[7] Junghahn, *Ber.*, **35**, 3762 (1902).

[8] Raschig, German pat., 283,306, *Chem. Zentr.*, I, 926 (1915).

[9] Jahns, *Archiv. Pharm.*, **215**, 6 (1879); Claus and Fahrion, *J. prakt. Chem.*, [2] **39**, 356 (1889); Paterno, *Gazz. chim. ital.*, **5**, 21 (1875); Carstanjen, *J. prakt. Chem.*, [2] **15**, 410 (1877).

[10] Claus and Krause, *ibid.*, [2] **43**, 345 (1891).

[11] Engelhardt and Latschinow, *Z. Chem.*, 46 (1869).

[12] Lallemand, *Ann. chim.*, [3] **49**, 150 (1857); Stebbins, *J. Am. Chem. Soc.*, **3**, 103, 110 (1881); **21**, 276 (1899).

[13] Mazurowska, *J. prakt. Chem.*, [2] **13**, 172 (1876).

[14] Reuter, *Ber.*, **11**, 30 (1878); Krohn, *Ber.*, **21**, 886 (1888).

[15] Jacobsen, *Ann.*, **195**, 270 (1879).

[16] Schroeter and co-workers, *Ann.*, **426**, 83 (1922).

[17] Green and Rowe, *J. Chem. Soc.*, **113**, 967 (1918).

Sulfonation of Alkylphenol Ethers. The sulfonation of the ethers of phenol has already been discussed. In Table VII are tabulated the results for other aryl alkyl ethers.

TABLE VII

SULFONATION OF ALKYLPHENYL ALKYL ETHERS

Compound Sulfonated	Reagent and Reference	Reaction Data	Position of Sulfo Group
2-Tolyl methyl	A^{1}	....	4- (?)
	C^{11}	$CHCl_3$ sol.	4-SO_2Cl
3-Tolyl methyl	A or $C^{2,\,11}$	....	4-, then 4,6-di-
4-Tolyl methyl	A^{3}	100°	2-
	$C^{4,\,11}$	....	2-SO_2Cl
2-Tolyl ethyl	C^{11}	$CHCl_3$ sol.	4-SO_2Cl
3-Tolyl ethyl	C^{11}	$CHCl_3$ sol.	4-SO_2Cl
4-Tolyl ethyl	A^{5}	100°	2-
	C^{11}	$CHCl_3$ sol.	2-SO_2Cl
4-Tolyl *n*-propyl	C^{11}	$CHCl_3$ sol.	2-SO_2Cl
2-Tolyl *n*-butyl	C^{11}	$CHCl_3$ sol.	4-SO_2Cl
2-Tolyl dodecyl	A^{12}	70°	4-
4-Tolyl dodecyl	A^{12}	70°	2-
2-Tolyl cetyl	A^{12}	70°	4-
3-Tolyl cetyl	A^{12}	70°	4-
4-Tolyl cetyl	A^{12}	70°	2-
3-*n*-Propylphenyl ethyl	A^{6}	....	4- (?)
4-*n*-Propylphenyl methyl	A^{7}	....	2-
4-*n*-Propylphenyl ethyl	A^{6}	....	2-
4-Octylphenyl octyl	A^{10}	....	(?)
5-Isopropyl-2-methyl-phenyl methyl	A^{8}	25°	4- and 6-
2-Isopropyl-5-methyl-phenyl methyl	$A^{8,\,9}$	....	4- and 6-
2-Isopropyl-5-methyl-phenyl ethyl	A^{9}	....	4-
2-Isopropyl-5-methyl-phenyl isoamyl	A^{9}	....	4- and 6-
?-*tert*-Pentylphenyl methyl	A^{13}	....	?

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[1] Bromwell, *Am. Chem. J.*, **19**, 569 (1897).

[2] Haworth and Lapworth, *J. Chem. Soc.*, **123**, 2982 (1923); **125**, 1299 (1924).

[3] Alleman, *Am. Chem. J.*, **31**, 27 (1904).

[4] Stewart, *J. Chem. Soc.*, **121**, 2555 (1922); Gibson and Smiles, *ibid.*, **123**, 2388 (1923).

[5] Roberts and Alleman, *J. Am. Chem. Soc.*, **33**, 393 (1911).

[6] Klages, *Ber.*, **37**, 3990 (1904).

[7] Klages, *Ber.*, **32**, 1438 (1899).

[8] Paterno, *Gazz. chim. ital.*, **5**, 20 (1875); *Ber.*, **8**, 440 (1875).

[9] Engelhardt and Latschinow, *Z. Chem.*, 47 (1869).

[10] I. G. Farbenind. A.-G., British pat., 495,414, *C.A.*, **33**, 3030 (1939).

[11] Huntress and Carten, *J. Am. Chem. Soc.*, **62**, 603 (1940).

[12] Hartley, *J. Chem. Soc.*, 1828 (1939).

[13] Borglin, U. S. pat., 2,245,643, *C.A.*, **35**, 6023 (1941).

Sulfonation of Esters of Phenols. The sulfonation of several phenyl esters has already been mentioned (see p. 233). An interesting development utilizing this class of compounds concerns the carbethoxy esters. Sulfonation of these compounds with chlorosulfonic acid [324a] may be controlled so as to produce monosulfonyl chlorides, a reaction difficult to achieve with other phenol derivatives. Thus, carbethoxy *m*-cresol slowly added to five parts of chlorosulfonic acid and allowed to stand for 3 hours gives the 4-sulfonyl chloride. Other aryl carbethoxy esters behave similarly. Aryl esters of high-molecular-weight fatty acids when sulfonated yield washing agents.[324b]

Sulfonation of Halophenols and Halonitrophenols. The members of this group of compounds (together with several ethers derived from them) which have been sulfonated are listed in Table VIII in the usual manner. One compound in this group deserves special mention. Chlorosulfonic acid does not react with 2,4-dibromo-5-methylphenyl methyl ether [325] at room temperature. At 70° oleum reacts to give as one product tribromo-*m*-cresol. This was also obtained when the dibromo-m-cresol was the starting material. With chlorosulfonic acid dibromo-*m*-cresol gives the aryl hydrogen sulfate.

Sulfonation of Hydroxycarboxylic Acids. Salicylic acid has been sulfonated by a number of procedures all of which give the same sulfonic acid or its acid chloride, the position *para* to the hydroxyl group reacting.[326] Of the various methods making use of sulfuric acid [327] the most efficient consists in dissolving 100 g. of salicylic acid in 200 ml. of sulfuric acid containing 3% sulfur trioxide. Upon standing, 160 g. of the sulfosalicylic acid crystallizes from the reaction mixture. This acid is also formed through the action of one molecular equivalent of sulfur trioxide gas [328] or chlorosulfonic acid,[329] the latter at 160°, upon salicylic acid; and from hot sulfuric acid [330] and phenyl salicylate (salol). With excess chlorosulfonic acid at 180° a disulfonic acid results, whereas at 30–40° the monosulfonyl chloride [186, 331] is isolated in 60% yield. In a similar manner, methyl salicylate, and 3-chloro-, 5-chloro-, 4-carboxy-, 3-methyl-, 4-methyl-, and 5-methylsalicylic acids all yield monosulfonyl chlorides, substitution occurring *para* to hydroxyl except when this position is already occupied. With fluorosulfonic acid [27a] salicylic acid gives the sulfonyl fluoride. Sulfonation of *o*-methoxybenzoic acid [327c] gives the same product as methylation of sulfosalicylic acid.

m-Hydroxybenzoic acid, in contrast to the *ortho* isomer, sulfonates *ortho* to the hydroxyl group when treated with sulfur trioxide.[332] The isomeric compound obtained from the action of sulfuric acid upon *m*-carboxybenzenediazonium sulfate [333] must then have the *para* struc-

TABLE VIII

SULFONATION OF PHENOL DERIVATIVES

Compound Sulfonated	Reagent* and Reference	Reaction Data	Position of Sulfo Group
4-Fluoro- methyl ether	C[17]	$CHCl_3$ sol.	2-SO_2Cl
2-Chloro-	B[1a]	"Warm"	4- (?)
	B[1a]	"Cold"	4- and 2-
2-Chloro- methyl ether	C[1b, 17]	50°	4- and 4,4′-sulfone
3-Chloro-	A[2], 1.66 parts	100°, 8 hrs.	6-
	B[2], 27%	100°, 2 hrs.	4,6-di-
4-Chloro-	A[3], 1 mole	....	2-
	B[3]	100°	2,6-di-
4-Chloro- methyl ether	C[3b, 17]	"Cold"	2-SO_2Cl
2,4-Dichloro-	C[4], 1 mole	In CS_2	6-
2-Bromo- methyl ether	C[17]	$CHCl_3$ sol	4-SO_2Cl
4-Bromo- methyl ether	C[17]	$CHCl_3$ sol.	2-SO_2Cl
2-Chloro- ethyl ether	C[17]	$CHCl_3$ sol.	4-SO_2Cl
4-Chloro- ethyl ether	C[17]	$CHCl_3$ sol.	2-SO_2Cl
2-Bromo- ethyl ether	C[17]	$CHCl_3$ sol.	4-SO_2Cl
4-Bromo- ethyl ether	C[17]	$CHCl_3$ sol.	2-SO_2Cl
3-Methyl-4-chloro-	A[5]	70–110°	6-
3-Methyl-4-bromo-	A[6]	70°	6-
2-Methyl-4-bromo-	B[7]	100°	6-
2-Nitro-	B[8], 3.5 parts	100°	4- and 6- (trace)
	C[8c, 9]	In CS_2	4-
	FSO_3H[14]	....	4-SO_2F
2-Nitro- methyl ether	C[10]	....	4-
3-Nitro-	B[8c]	90°	6- (?)
4-Nitro-	B[11], excess	"Cold"	2-
	A[8c]	5° with diatomaceous earth	2-
	C[12], 2 moles	100°	2- (poor yield)
2-Nitro-3-chloro-	B[15], 30%	20°	4-
6-Nitro-3-chloro-	B[15], 30%	20°	4-
4-Nitro-3-chloro-	B[15]	....	Decomposition only
2-Methyl-6-nitro-	A[13], 2 parts	"Warm"	4-
3-Methyl-6-nitro-	A[13], 4 parts	70°, 6 hrs.	4-
4-Methyl-2-nitro-	B[13]	0°	6-

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* See p. 236 for meaning of *A*, *B*, and *C*.

[1] (*a*) Kramers, *Ann.*, **172**, 331 (1874). (*b*) Child, *J. Chem. Soc.*, 715 (1932).

[2] Hodgson and Kershaw, *ibid.*, 2923 (1929); 1419 (1930).

[3] (*a*) Peterson and Baehr-Predari, *Ann.*, **157**, 130 (1871). (*b*) Gauntlett and Smiles, *J. Chem. Soc.*, **127**, 2745 (1925).

[4] Armstrong, *ibid.*, **25**, 93 (1872).

[5] v. Walther and Demmelmeyer, *J. prakt. Chem.*, [2] **92**, 108 (1915).

[6] v. Walther and Demmelmeyer, *ibid.*, [2] **92**, 125 (1915).

[7] Claus and Jackson, *ibid.*, [2] **38**, 325 (1888).

[8] (*a*) Kekulé, *Z. Chem.*, 641 (1867). (*b*) Armstrong and Brown, *Ber.*, **7**, 924, 1025 (1874). (*c*) Gnehm and Knecht, *J. prakt. Chem.*, [**2**] **73**, 521 (1906).

[9] Masurowska, *ibid.*, [2] **13**, 171 (1876); Armstrong, *J. Chem. Soc.*, **24**, 175 (1871).

[10] Gnehm and Knecht, *J. prakt. Chem.*, [2] **74**, 92 (1906).

[11] Post, *Ber.*, **5**, 853 (1872); *Ann.*, **205**, 38 (1880); Korner, *Gazz. chim. ital.*, **2**, 445 (1872).

[12] Gordon, *Chem. News*, **63**, 222 (1891).

[13] Schultz, *Ber.*, **40**, 4319 (1907).

[14] Steinkopf and co-workers, *J. prakt. Chem.*, [2] **117**, 1 (1927).

[15] Hodgson and Kershaw, *J. Chem. Soc.*, 2169 (1930).

[16] Weiler and Retter, German pat., 557,450, *C.A.*, **27**, 735 (1933).

[17] Huntress and Carten, *J. Am. Chem. Soc.*, **62**, 603 (1940).

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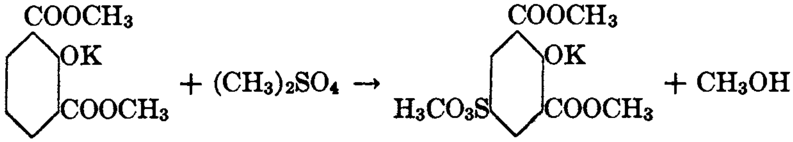
ture. With a mixture of 50% oleum and phosphorus pentoxide[334] at 250° for 8 hours *m*-hydroxybenzoic acid gives the 2,4,6-trisulfonic acid.

p-Hydroxybenzoic acid monosulfonates with five parts of sulfuric acid[335] at 100° or with one molecular equivalent of sulfur trioxide.[336] The methyl ether, anisic acid, is readily sulfonated with oleum[337] at 100°, giving 3-sulfo-4-methoxybenzoic acid.

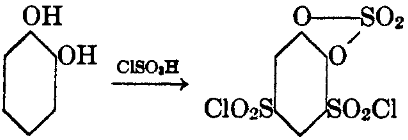
β-(4-Hydroxyphenyl)-propionic acid has been sulfonated with sulfur trioxide[338a] to what is undoubtedly the 3-sulfo compound, although its structure was not established. Tyrosine[338b] reacts in a similar manner.

Sulfonation of Hydroxydicarboxylic Acids. By the action of chlorosulfonic acid upon 4-hydroxy-1,3-benzenedicarboxylic acid[338c] at 90° the 5-sulfonyl chloride results. An interesting sulfonation is that occurring through the action of methyl sulfate[338d] upon the potassium salt of dimethyl 2-hydroxyisophthalate.

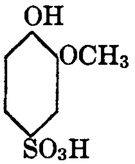


Sulfonation of Catechol and Its Derivatives. The action of sulfuric acid on catechol, either at room temperature or 100°, gives a sulfonic acid which was first[339] believed to be the 3-isomer. That it was actually catechol-4-sulfonic acid followed from its identity with the sulfonic acid obtained by fusion of phenol-2,4-disulfonic acid with alkali,[340] and its conversion on methylation into 3,4-dimethoxybenzenesulfonic acid whose structure has been demonstrated by an independent synthesis. Ammonium catechol-4-sulfonate results from heating catechol with sulfamic acid.[341] It is not possible to introduce two sulfo groups with this reagent.

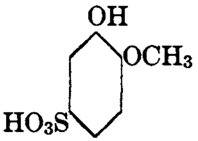
By the action of 30% oleum[339] at 100°, or chlorosulfonic acid[342] at room temperature, the 3,5-disulfonic acid is formed. By heating with ten parts of chlorosulfonic acid at 110° for 1.5 hours and pouring the reaction mixture into hydrochloric acid the disulfonyl chloride results, while at 150° a cyclic sulfate of the disulfonyl chloride is produced in good yield.



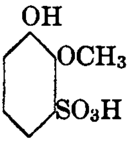
Study of the sulfonic acids of the monomethyl ether of catechol (guaiacol) has been intensive because of the supposed therapeutic value of one of the compounds (Thiocol) and the peculiarities attending the sulfonation reaction. Sulfuric acid up to 100°, or even higher if the reaction is not allowed to proceed more than a few minutes, gives a mixture containing nearly equal quantities of two sulfonic acids[343, 344] which are convertible by methylation into the same dimethoxy compound.[345] Synthesis of one of these acids showed that their structures must be I and II.



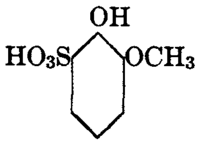
I
Lower-melting acid



II
Higher-melting acid



III



IV

It was claimed by Rising[346] that both of these acids undergo rearrangement upon heating into a third acid which would be III or IV. This acid is also formed by the sulfonation of guaiacol at 135–140° for 3 hours with sulfuric acid. Paul[347] demonstrated that this acid was actually catechol-4-sulfonic acid, demethylation occurring under these reaction conditions. The guaiacolsulfonic acid of Barell[348] is also catechol-4-sulfonic acid.

The commercial product Thiocol is a mixture of the mono and dipotassium salts of I and II. Methods for the analysis of Thiocol have been investigated.[349]

Sulfonation of guaiacol carbonate gives a disulfonic acid[350] whose structure corresponds to the higher-melting guaiacolsulfonic acid, II.

Catechol dimethyl ether (veratrole) with sulfuric acid or oleum[351] is converted into the 4-sulfonic acid. This upon heating with aqueous alkali to 180–200° produces guaiacol-4-sulfonic acid.[352] The diethyl ether behaves similarly. Through the action of chlorosulfonic acid[290,353] in chloroform solution veratrole and the diethyl ether are converted into the 4-sulfonyl chlorides. The di-*n*-octyl ether[303d] reacts readily with sulfuric acid at 70°.

Sulfonic acids have been prepared from 4-methylcatechol[339] and 2-methoxy-4-methylphenol[354] but their structures were not determined. The acid obtained from the reaction of oleum[339] upon 4-methylcatechol dimethyl ether is likewise of unknown structure, but chlorosulfonic acid[353] with this compound gives 3,4-dimethoxytoluene-6-sulfonyl chloride hence the sulfonic acid probably has the same structure.

Sulfonation of Resorcinol and Its Derivatives. Treatment of resorcinol with an equimolecular amount of sulfuric acid at room temperature[355] produces the 4-sulfonic acid. The ammonium salt of this acid is formed by heating resorcinol with sulfamic acid.[341] By heating with oleum[356] at 100° resorcinol is converted into the 4,6-disulfonic acid. This has also been obtained by the action of chlorosulfonic acid[357] in carbon disulfide at 0° or room temperature using as much as five parts of chlorosulfonic acid to one of resorcinol. With ten parts of the sulfonating agent at room temperature a 90% yield of the disulfonyl chloride resulted when no solvent was used, whereas at 110° with a large excess of chlorosulfonic acid the 2,4,6-trisulfonyl chloride was obtained.

Ammonium resorcinol-4-sulfonate when heated with sulfamic acid produces the 4,6-disulfonate.[341] Heating resorcinol-4,6-disulfonic acid with oleum at 200° converts it into the 2,4,6-trisulfonic acid.[358]

Treating 4-nitroresorcinol with sulfuric acid[359] at 80–90° gives besides the 6-sulfonic acid a nitrohydroxyphenyl ether. Warming 2,4-dihydroxybenzoic acid with five parts of sulfuric acid[360] at 100° results in sulfonation, probably in the 5-position.

Sulfonation of the monoalkyl ethers of resorcinol has apparently not been investigated. The dimethyl ether is converted practically quantitatively into the 4-sulfonic acid by warming for an hour with two molecular equivalents of sulfuric acid.[361a] Chlorosulfonic acid in chloroform gives the 4-sulfonyl chloride of both the methyl and ethyl ethers.[290] By a more vigorous sulfonation the 4,6-disulfonic acid results.[361b] The sulfonation of high-molecular-weight ethers and esters of resorcinol produces compounds useful as wetting agents.[362] These compounds have been studied in some detail by Hartley.[303d]

5-Methylresorcinol (orcinol) with sulfuric acid[363] yields a monosulfonic acid.

Sulfonation of Hydroquinone and Its Derivatives. Sulfonation of hydroquinone with a mixture of sulfuric acid and oleum at a temperature of not over 50° yields the monosulfonic acid.[364] The kinetics of this sulfonation reaction have been studied for various concentrations of sulfuric acid [365] over the temperature range 50–100°. Sulfuric acid monohydrate, $H_2SO_4 \cdot H_2O$, is capable of introducing one sulfo group, whereas for a second the anhydrous acid and temperatures above 100° are necessary. Over the concentration range of 7 to 14 molar sulfuric acid the logarithm of the rate of sulfonation is proportional to the concentration of the acid.

A hydroquinonedisulfonic acid is made by the use of oleum [366] or sulfuric acid [364] by heating at 100–110° for an hour. The structure of this acid is undetermined and is different from the one obtained by the action of oleum [367] on quinic acid. Hydroquinone is disulfonated by heating with sulfamic acid [341] to what is probably a mixture of the 2,5- and 2,6-isomers.[368] Chlorosulfonic acid likewise [369] brings about disulfonation when used in excess at a temperature of 80°. The 2,5- and 2,6-disulfonyl chlorides are formed, the latter in larger amount. At room temperature no reaction occurs with this reagent.

Hydroquinone dimethyl ether with sulfuric acid [370] at 125° yields the monosulfonic acid. The methyl and ethyl ethers both give sulfonyl chlorides with chlorosulfonic acid.[299] Higher ethers yield wetting agents on sulfonation.[303d, 362]

Chlorohydroquinone when treated with 15% oleum [371] below 50° gives a sulfonic acid isomeric with the one obtained from quinonesulfonic acid and hydrochloric acid. Bromohydroquinone behaves similarly.[372] 2,5-Dihydroxybenzoic acid with five times its weight of sulfuric acid and an equal weight of phosphorus pentoxide [373] at 130° is monosulfonated to what would be predicted to be the 3-sulfonic acid. Its structure was, however, not established.

Sulfonation of Polyhydroxyphenols. 1,2,3-Trihydroxybenzene (pyrogallol) with either pyrosulfuric acid [374] or sulfuric acid [375, 378] at 100° yields the 4-sulfonic acid. A disulfonic acid of uncertain structure results from more vigorous sulfonation.[377] Since with chlorosulfonic acid the product is the 4,6-disulfonyl chloride,[378] the disulfonic acid probably has this structure also. The 1,3-dimethyl, the trimethyl, and the triethyl ethers [379] have been monosulfonated. The trimethyl ether yields the 4-sulfonyl chloride with chlorosulfonic acid.[299] Oleum [380] converts gallic acid into a monosulfonic acid.

1,3,5-Trihydroxybenzene (phloroglucinol) has been sulfonated by treatment with the theoretical amount of pyrosulfuric acid.[381] With ten parts of chlorosulfonic acid [382a] at room temperature the trisulfonic acid is formed, while with fifty parts of the sulfonating agent after several days' standing a disulfonyl chloride is obtained. This same chloride resulted whether the starting material was phloroglucinol or its trisulfonic acid.

Hydroxyhydroquinone trimethyl ether sulfonates readily to the 5-sulfonic acid.[382b] The acid chloride, amide, and anilide were prepared. The 6-sulfonic acid was prepared by an indirect method starting with the sulfonation of vanillin.

SULFONATION OF AROMATIC AMINES

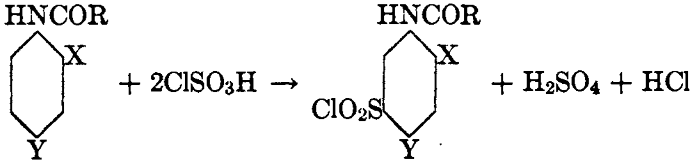
Many of the sulfonic acids containing amino groups are of value as dye intermediates. Since most of these compounds are prepared by the sulfonation of amines, the literature dealing with the reactions of this type is extensive. In this section the discussion will be limited to amino derivatives of benzene and its substitution products.

In the "baking process" for the preparation of an aminosulfonic acid[383] the acid sulfate of an amine is heated to 180° or higher for several hours, preferably under reduced pressure; sulfonation in the benzene series, with rare exceptions, occurs *para* to the amino group unless this position is already occupied, whereupon the *ortho* position is sulfonated. The yields obtained by this method are excellent, as is shown by the work of Huber[383] who obtained from 89 to 98% yields of sulfonic acids from a variety of amines, including aniline, the toluidines, 3,4-dimethylaniline, 2,5-dimethylaniline, the naphthylamines, dehydrothiotoluidine, and 1-aminoanthraquinone.

By the action of an excess of oleum at a low temperature many amines may be converted into the *m*-sulfonic acids. For aniline[384] the evidence is somewhat conflicting but for compounds in which a methyl or halogen is in a position that directs the entering substituent *meta* to the amino group a *meta* sulfonic acid is always an important component of the reaction product. The sulfonation of N-alkylamines at low temperatures gives *meta* compounds even without the presence of another group in the ring. For *p*-toluidine it has been reported[385] that the 3-amino-6-methylbenzenesulfonic acid may be obtained even at 180° although a low temperature is more frequently favorable to *meta* sulfonation. Apparently no systematic investigation of the effect of temperature upon directive influence in the sulfonation of amines has been undertaken. A quantitative method for distinguishing between *ortho-para* and *meta* sulfonation is available in that bromine replaces the former sulfo groups but not the latter.[386]

The action of one molecular equivalent of chlorosulfonic acid upon an amine dissolved in an inert solvent such as carbon tetrachloride or acetylene tetrachloride has been patented as a process for making *o*-aminosulfonic acids. The first use of the method was in the sulfonation of anthranilic acid,[387] which, however, gave the *p*-sulfonic acid. A little later it was claimed [388] that a group of amines including aniline, *p*-toluidine, α-naphthylamine, *p*-chloroaniline, dehydrothiotoluidine, *o*-anisidine, 3,4-dimethylaniline, 2,4-dimethylaniline, *p*-nitraniline, 3,5-dichloroaniline, 2,4-dichloroaniline, 3,4-dichloroaniline, 3-chloro-4-methylaniline, and chloro-*o*-anisidine all gave *o*-sulfonic acids. More recently it has been shown [389] that with aniline no more than a trace of orthanilic acid results from this method of sulfonation. This finding casts doubt upon the structures assigned to the other sulfonic acids obtained from amines in which the position *para* to the amino group is unoccupied. This same method has been further [390] applied to the preparation of *o*-sulfonic acids from amines substituted in the 3,4,6-positions by a variety of substituents including alkyl, alkoxy, arylketo, arylsulfonyl, nitro, sulfo, carboxy, and chloro groups. From a consideration of the compounds given as examples it is probable that here all the sulfonic acids are actually of the *ortho* structure. Later [391] the process was broadened to include amines substituted in the 3,4,5-positions and optionally in the 6-position. Amines substituted in the 3,5,6-positions with position 2- filled or not give *p*-sulfonic acids.

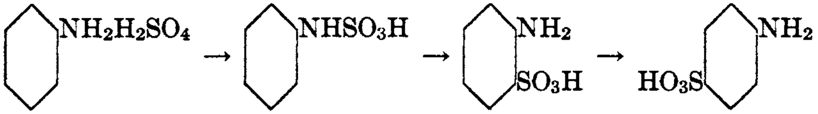
By the action of an excess of chlorosulfonic acid upon anilides of the general formula shown, sulfonyl chlorides are produced [392] in which sulfonation occurs *meta* to the amide group.



Here Y is methyl, hydrogen, halogen, or an alkoxy group and X is methyl, halogen, or alkoxy, except that compounds where X is halogen and Y is hydrogen or halogen are excluded. The acyl group may also be aromatic. A large number of specific examples is described in the patent.

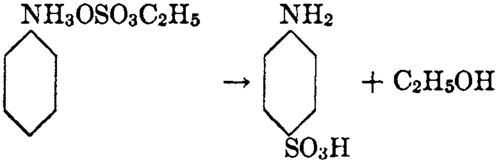
A sulfonation method analogous to that using chlorosulfonic acid and a solvent calls for sulfonation with sulfur trioxide in acetylene tetrachloride,[393] 2,4-dimethylaniline, for example, yielding the 6-sulfonic acid.

Considerable attention has been devoted to a study of the mechanism by which aminosulfonic acids are formed. It has been found [894] that phenylaminosulfonic acid rearranges in cold acetic acid solution with a trace of sulfuric acid to aniline-*o*-sulfonic acid, while the free acid or its salts [895] alone give sulfanilic acid. It was further reported that the *o*-sulfonic acid rearranged [894] when heated with sulfuric acid into the *para* isomer. From this evidence Bamberger suggested that the formation of sulfanilic acid proceeded through the following steps.



Although phenylaminosulfonic acid has apparently not been obtained from the action of sulfuric acid with aniline, other sulfonating agents do give this as the primary product. Thus, the sulfur trioxide addition compound of pyridine [896] or dioxane [897] reacts readily with the amino group at ordinary temperature while high-temperature sulfonation gives sulfanilic acid, undoubtedly by rearrangement of the phenylaminosulfonic acid first formed. Bamberger's postulation that the *ortho* sulfonic acid is an intermediate in the reaction is not in accord with the absence of any appreciable amount of this compound from the product obtained by the sulfonation of aniline with oleum at 0°. It is also not likely that the arylaminosulfonic acid is an intermediate in *meta* sulfonation as no *meta* rearrangements are known. It was remarked by Armstrong and Berry [884] that aniline sulfate did not react with chlorosulfonic acid at 35–40° and hence that formation of phenylaminosulfonic acid does not occur at low temperatures when the amine is present as a salt. It has also been observed that some amines form salts with chlorosulfonic acid,[888] hydrogen chloride being evolved only when the reaction mixture is heated. It may well be that the sulfonation mechanism for the baking process of preparing aminosulfonic acids is quite different from that for a sulfonation in the presence of an excess of sulfonating agent. Bamberger's theory, with the deletion of the *o*-sulfonic acid as an intermediate, seems more plausible for the baking process. Even here, however, formation of the arylaminosulfonic acid is not essential for the reaction to proceed since dimethylaniline hydrogen sulfate [898] goes over to the *p*-sulfonic acid as readily as does the aniline salt.

Sulfonation of Aniline. From the reaction mixture produced by heating aniline with three molecular equivalents of sulfuric acid for 5 hours at 180–190° a 60% yield of pure sulfanilic acid may be obtained.[399] The low solubility of the acid in cold water facilitates its separation from excess sulfuric acid and any disulfonation products. For large-scale preparations undoubtedly the most economical procedure is the heating of aniline hydrogen sulfate[383,398,400] at 180° for 8 hours. Sulfanilic acid is formed by boiling aniline with two parts of oleum[399a,401] for a few minutes but considerable decomposition occurs. Sulfonation has likewise been effected by heating aniline with sodium trihydrogen disulfate[402] at 200° or with potassium bisulfate[403] at 240°. Sulfanilic acid is one of the products obtained from the action of ethyl chlorosulfonate upon aniline.[404] It is also formed by heating the aniline salt of ethyl hydrogen sulfate.[405]



Surprisingly enough, heating the aniline salt of any of the three phenolsulfonic acids[406] to 180–190° results in a distillate of pure phenol and a residue which is chiefly sulfanilic acid.

The disulfonation of aniline has usually been performed in two steps. Sulfanilic acid when heated with oleum[401a,407] at 160–180° for 5 to 7 hours is converted to the 2,4-disulfonic acid; its structure is evident as it also results from the sulfonation of orthanilic acid. The disulfonation is also readily effected by chlorosulfonic acid.[408] By heating aniline to 150° with a large excess of this reagent it has also been possible to prepare the trisulfonic acid.[409] If sodium chloride is present in the reaction mixture, the trisulfonyl chloride is the main product.

The sulfonation of metanilic acid offers an example of substitution occurring *ortho* to an amino group, the 2,5-disulfonic acid being the sole product.[407,410]

Sulfonation of Anilides. The sulfonation of an anilide may or may not result in the removal of the acid radical, depending upon the reagent and the reaction conditions. Gerhardt[400] first prepared sulfanilic acid by heating the crude mixture of oxanilide and formanilide, formed from aniline and oxalic acid, with sulfuric acid. In later work it was found possible[411] to sulfonate oxanilide to the 4,4′-disulfonic acid without difficulty. Acetanilide is converted into the 4-sulfonic acid by the action of oleum[412] or sulfuric acid in acetic anhydride.[413] With five molecular equivalents of chlorosulfonic acid at 60° for 2 hours acylanilides give the corresponding sulfonyl chlorides[414] in 80%

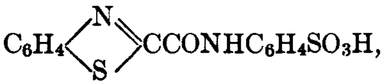
yields while at higher temperatures the products are the same as for aniline.[409] Acetanilide-*p*-sulfonyl chloride and similar compounds are of importance as intermediates in the synthesis of sulfanilamide and many related sulfonamides.

Anilides of high-molecular-weight fatty acids when sulfonated yield surface-active agents of value as detergents or wetting agents.[415]

Benzanilide with sulfur trioxide [416a] gives only a small yield of the *p*-sulfonic acid, sulfonation occurring in the ring attached to nitrogen. Methyl phenylcarbamate is converted by the action of oleum [416b] into the *p*-sulfonic acid. Acetylphenylurea ($CH_3CONHCONHC_6H_5$) [416c] with chlorosulfonic acid gives the *p*-sulfonyl chloride.

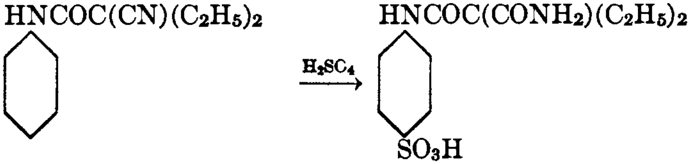
Benzenesulfonanilide upon standing with sulfuric acid [417] gives sulfanilic acid, but *p*-toluenesulfonanilide has been sulfonated with pyridine-sulfur trioxide [418] by heating at 180–190° for 6 to 8 hours without affecting the amide linkage, a 100% yield of the *p*-sulfonic acid being recovered.

Diphenylurea upon standing with sulfuric acid gives sulfanilic acid.[419] Thiooxanilide,[420] $C_6H_5NHCOCSNHC_6H_5$, is transformed into a mixture of substances including sulfanilic acid, the sulfonation product, $C_6H_5NHCSCONHC_6H_4SO_3H$-4, and the benzothiazole,



$$C_6H_4\overset{N}{\underset{S}{\diamond}}CCONHC_6H_4SO_3H,$$

derived from it by ring closure. By treatment of diethylcyanoacetanilide with sulfuric acid [421] the cyano group is hydrolized to the amide and the ring is sulfonated.

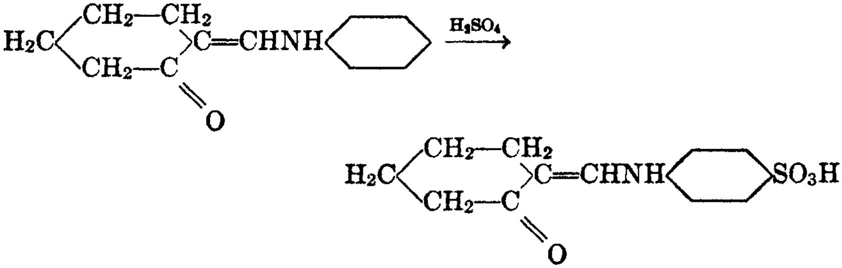


A phosphorus derivative of aniline, $(C_6H_5NH)_4PCl$, when treated with sulfuric acid [422] and poured into water yields a tetrasulfonic acid with the formula $(HO_3SC_6H_4NH)_4POH$.

Sulfonation of N-Alkylanilines. A few secondary and tertiary amines derived from aniline have been sulfonated. Methylaniline with oleum [423] above 150° gives the 4-sulfonic acid while at a temperature below 50° it is possible to obtain an appreciable yield [423a, d, 424] of the 3-isomer. N-Ethylaniline [423a, 425, 426] behaves similarly. Heating

N-methylacetanilide with sulfuric acid [379] at 140–150° unexpectedly produces 2-methylaminobenzenesulfonic acid,[423c, 427] the acetyl group being detached to form methanedisulfonic acid. The same amino acid results from heating methylanilinium ethyl sulfate.[428a, 428] As already noted,[398] dimethylanilinium hydrogen sulfate is converted into the *p*-sulfonic acid by the baking process while heating with oleum transforms either dimethylaniline [429] or diethylaniline [429] into a mixture of the *meta* and *para* sulfonic acids. The sulfonic acid obtained from the high-temperature sulfonation of methylethylaniline [398a, 430a] is probably the *para* isomer. Long-chain N-alkylanilinesulfonic acids have been prepared [430b] as wetting and cleaning agents.

Sulfonation of the complex amine, 2-phenyliminomethylene-cyclohexanone, with sulfuric acid [431] gives the *p*-sulfonic acid.

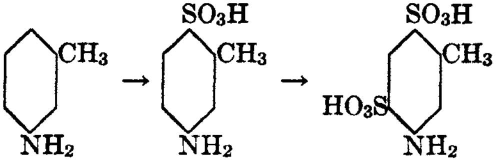


The sulfonic acids derived from diphenylamine are discussed under systems containing two benzene rings.

Sulfonation of the Toluidines. Sulfonation of *o*- and *p*-toluidine has been investigated by many workers. Heating *o*-toluidine to 180° with two molecular equivalents of 20% oleum [432] for 10 hours gives a 78% yield of the 3-methyl-4-aminobenzenesulfonic acid. The use of iodine as a catalyst was found to be undesirable [433] as it leads to side reactions. The preparation of this acid by the baking process has already been described.[388] By sulfonating *o*-toluidine sulfate with 30%, or two parts of 50%, oleum [384, 434] below 0° the 3-amino-4-methylbenzenesulfonic acid becomes the main product. With chlorosulfonic acid at 160° this is further sulfonated to 4-methyl-5-aminobenzene-1,2-disulfonic acid which is of interest in that formation of *o*-disulfonic acids by direct sulfonation is unusual. The 4-amino-3-methylbenzenesulfonic acid is further sulfonated by oleum at 150–170° to 4-amino-3-methylbenzene-1,5-disulfonic acid.[435]

m-Toluidine is converted into a mixture of the 6-mono- and a disulfonic acid by treatment with three parts of oleum [433] at 160–175°.

With four parts of 20% oleum[437] at 125° for 8 hours a high yield of the 6-sulfonic acid results.



p-Toluidine behaves similarly to the o-isomer in that two monosulfonic acids are obtainable. The 2-methyl-5-aminobenzenesulfonic acid is obtained by sulfonation with 50% oleum[384] at 0° or by heating with 2.5 parts of 14% oleum[438] at 180°. If the heating is continued only until the odor of sulfur dioxide becomes evident,[385] however, the chief product is the isomeric 2-amino-5-methylbenzenesulfonic acid while a longer reaction time leads to the conversion of this into the acid first mentioned and into 2-amino-5-methylbenzene-1,3-disulfonic acid.[433] This disulfonic acid has also been obtained by the action of chlorosulfonic acid[439] upon 2-amino-5-methylbenzenesulfonic acid at 140–160°. Further sulfonation of the 2-methyl-5-aminobenzenesulfonic acid with either oleum or chlorosulfonic acid gives the 1,4-disulfonic acid.[439] The action of a large excess of chlorosulfonic acid[409] gives a disulfonyl chloride. Separation of the two monosulfonic acids may be effected by the difference in their solubilities in alcohol,[440a] the solubilities of their lead salts in water,[385] or their potassium salts in cold aqueous potassium hydroxide.[440b]

The effect of various sulfonating agents upon a number of derivatives of the toluidines is given in Table IX. The abbreviations used here are the same as for previous tables of this type. In Table X are similarly tabulated the results obtained in sulfonation of the xylidines and a few higher alkyl derivatives of aniline. The sulfonation of some of these compounds and others of similar nature has already been referred to under the general discussion of sulfonation reactions for amides (see p. 246).

A series of long-chain *p*-alkylanilinesulfonic acids has been described in the patent literature.[441a] α-Alkylbenzylamines[441b] also have been sulfonated to give products useful in the textile industry.

Sulfonation of Nitro- and Haloaminobenzenes. The number of known halogen and nitro derivatives of aminosulfonic acids is not large, and of these most of the bromine compounds and all the iodine derivatives have been made by methods other than direct sulfonation. The data dealing with those obtained by sulfonation reactions other than those already mentioned (see p. 246) are given in Table XI.

Sulfonation of Aminocarboxylic Acids. Anthranilic acid and its *meta* isomer together with their derivatives are apparently the only aminocarboxylic acids of the aromatic type that have been sulfonated. Anthranilic acid, treated with chlorosulfonic acid [887] in nitrobenzene, or with oleum [442] at 180° or lower, sulfonates *para* to the amino group. In the oleum reaction sulfanilic acid is obtained as a by-product.

TABLE IX

SULFONATION OF TOLUIDINE DERIVATIVES

Compound Sulfonated	Reagent and Reference	Reaction Data	Position of Sulfo Group
Toluene Substituents			
2-Methylamino-	*B*,[1] 20%; 4.5 parts	20–30°, then 50°	4-
	A[1]	180–200°, 10 hrs.	5- (?)
2-Dimethylamino-	*A*,[2] 4 parts	180–210°	5- (?)
	B,[3] 25%; 7 parts	5°	4-
2-Diethylamino-	*B*,[3] 25%; 10 parts	5°	4-
2-Acetylcarbamido	*C*[10]	10–15°	5-
3-Acetylcarbamido	*C*[10]	10–15°	6-
4-Ethylamino-	*B*[4]	....	2-
4-Diethylamino-	*B*[4]	....	2-
4-Acetamido-	*B*,[5] 20%	40°	2-
	C,[8] 5 moles	80°, 1 hr.	2- SO_2Cl
4-Carbamido-	*B*,[9] 10%	60°	3- (79%), 4- (trace)
2-Acetmethylamino-	*B*,[1] 20%	....	4-
4-(*p*-Toluenesulfonamido)-	*A*[6]	100°	4-$CH_3C_6H_3(SO_3H)NH_2$-2,1
Arylureas			
sym-Di-4-tolylurea	*A*[7]	150–160°	4-$CH_3C_6H_3(SO_3H)NH_2$-2,1

[1] Gnehm and Blumer, *Ann.*, **304**, 109 (1899).
[2] Michler and Sampaio, *Ber.*, **14**, 2168 (1881).
[3] Möhlau, Klimmer, and Kahl, *Chem. Zentr.*, II, 377 (1902).
[4] Schmidt, *J. prakt. Chem.*, [2] **48**, 62 (1893).
[5] Zincke and Rollhäuser, *Ber.*, **45**, 1498 (1912).
[6] Witt and Uermènyi, *Ber.*, **46**, 301 (1913).
[7] Cazeneuve and Moreau, *Bull. soc. chim.*, [3] **19**, 22 (1898).
[8] Johnson and Smiles, *J. Chem. Soc.*, **123**, 2384 (1923).
[9] Scott, *ibid.*, **123**, 3191 (1923).
[10] Cox, *J. Am. Chem. Soc.*, **62**, 744 (1940).

TABLE X

Compound Sulfonated	Reagent and Reference	Reaction Data	Position of Sulfo Group
Aniline substituents			
2,4-Dimethyl-	*B*,[1] 1.5 vol.	140–150°	5-
	B,[2] 20%	"Cold"	5-
	A,[3] excess	190°	5-
	C,[4]	"Hot"	5- and 6-
	A,[3, 5] 1 mole	1 hr. 220° or at 185–195°, 6 hrs.	6-
2,5-Dimethyl-	*A*[1c, 6] 0.9 parts	6 hr., 230°	4-
	A,[3] 1 mole	Heat in gas stream	4-
	B[1c, 5]	"Cold"	6-
3,4-Dimethyl-	*A*[7]	160–180°	5- and 6-
2,3-Dimethyl-	*A*[7]	160–180°	4- and 5-
2,4-Dimethylacet-	*B*,[8] 20%; 1.5 parts	140°	5-
2,5-Dimethylacet-	*B*,[8a] 20%; 3.25 parts	40°, 3 hr.	4-
2-Ethylacet-	*A*[12]	Heat	$2\text{-}C_2H_5C_6H_3(SO_3H)NH_2\text{-}4(?),1$
2-Methyl-4-isopropyl-	*B*[10]	....	5- (?)
2-Isopropyl-5-methyl-	*B*[11]	160–165°	4-
Arylureas			
Di-(2,4-dimethylphenyl) urea	*A*[9], 3 parts	160°	$(CH_3)_2C_6H_2(SO_3H)NH_2\text{-}5,1$
Di-(3,4-dimethylphenyl) urea	*A*[7]	160–180°	$(CH_3)_2C_6H_2(SO_3H)NH_2\text{-}6,1$

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[1] (*a*) Deumelandt, *Z. Chem.*, 22 (1866). (*b*) Jacobsen and Ledderboge, *Ber.*, **16**, 193 (1883). (*c*) Nölting and Kohn, *Ber.*, **19**, 138 (1886).

[2] Zincke and Maué, *Ann.*, **339**, 215 (1905).

[3] Junghahn, *Chem. Ind.* (German), **26**, 57 (1903).

[4] Junghahn, *Ber.*, **35**, 3749 (1902).

[5] Armstrong and Wilson, *Chem. News*, **83**, 46 (1901).

[6] Nölting, Witt, and Forel, *Ber.*, **18**, 2664 (1885).

[7] Simonsen, *J. Chem. Soc.*, **103**, 1150 (1913).

[8] (*a*) Junghahn, *Ber.*, **33**, 1365 (1900). (*b*) Moody, *Chem. News*, **65**, 60 (1892).

[9] Caseneuve and Moreau, *Bull. soc. chim.*, [3] **19**, 23 (1898).

[10] Kelbe and Warth, *Ann.*, **221**, 177 (1883).

[11] Widman, *Ber.*, **19**, 246 (1886).

[12] Paucksch, *Ber.*, **17**, 2803 (1884)

TABLE XI

Compound Sulfonated	Reagent* and Reference	Reaction Data	Position of Sulfo Group
Aniline substituents			
4-Fluoroacet-	*A*,[5b] 100%	170–180°, 2 hrs.	2-; (ACOH lost)
	B,[5b] 15%	145°, 15 min.	3-; (ACOH lost)
2-Chloro-	*A*,[1] 1 mole	160°, 30 min.	4-
3-Chloro-	*B*[2]	100°	6- and 4-
3-Chloroacet-	*A*[3]	....	4-
4-Chloro-	NH_2SO_3H,[4] 0.33 parts	230–250°	2- and 3- (trace)
	B,[5] 15%	145°, 15 min.	2- and 3-
	B[4, 6] 30–40%	"warm"	3-
2-Bromo-	*B*[7]	Heat	5-
4-Bromo-	$C_2H_5HSO_4$,[8] 1 mole	Heat	2-
4-Bromoacet-	*A*,[9] 2.5 parts	170–180°, 1 hr.	$4\text{-BrC}_6H_3(SO_3H)NH_2\text{-}2,1$
2,5-Dichloro-	*B*,[10] 18%, 3 parts	170–180°	4-
3,4-Dichloro-	*B*,[11] 23%	110–120°	6-
	A[11, 12]	200–215°	6-
3-Chloro-4-methyl-	*A*[13]	....	6-
2,3-Dichloro-4-methyl-	*A* or *B*[21]	170–200°	5-
2-Chloro-3-bromo-4-methyl-	*A* or *B*[21]	170–200°	5-
2-Nitro-	*B*,[14, 16] 10 parts	....	4-
3-Nitro-	*B*[14]	160° or 120–140°	6-
3-Nitro-4-chloro-	*B*[15]	170–180°	6-
3-Nitro-4-methyl-	*B* or *C*[17]	135–150° or 160°	6-
3-Nitro-2,4,5-trimethyl-	*C*[18]	165°	6-
Arylureas			
Di-(4-chlorophenyl) urea	*B*[19]	....	2-, 75%
Di-(4-bromophenyl) urea	*B*[20]	....	2-

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* *A* is sulfuric acid, *B* is oleum, and *C* is chlorosulfonic acid.

[1] Nölting and Battegay, *Ber.*, 39, 84 (1906).

[2] Post and Meyer, *Ber.*, 14, 1607 (1881); Claus and Bopp, *Ann.*, 266, 105 (1891).

[3] Badische Anilin- und Sodafabrik, German pat., 206,345, *Chem. Zentr.*, I, 964 (1909).

[4] Paal, *Ber.*, 34, 2753 (1901).

Acetylanthranilic acid and chlorosulfonic acid[409] at 200° yield a quinazoline derivative.

m-Aminobenzoic acid or the related diarylguanidine reacts with oleum[443] to give as the principal product 3-amino-4-sulfobenzoic acid, together with some 2-sulfo-5-aminobenzoic acid. The acids may be separated by crystallization of their barium salts from water. By the action of sulfuric acid at a high temperature[444] decarboxylation also occurs and sulfanilic acid is formed as a by-product.

2-Amino-5-chlorobenzoic acid[445] has been converted into a sulfonic acid that probably is substituted in the 3-position.

Two amino acids having the basic group in the side chain may also be mentioned here. α-Aminophenylacetic acid when treated with pyrosulfuric acid[446] at 120° is reported to sulfonate *meta* to the side chain while β-phenyl-α-aminopropionic acid with sulfuric acid at 100° gives the *para* compound.[447] The structure of the phenylacetic acid derivative was determined from the results of an alkali fusion.

Sulfonation of Diamino Compounds. Many complex derivatives of these compounds which contain sulfo groups are known, but sulfonation of the phenylenediamines or their substitution products has rarely been mentioned in the literature. The sulfonated diphenylamines related to the phenylenediamines are discussed in another section.

1,2-Diaminobenzene (*o*-phenylenediamine) hydrochloride when heated with 7.5 parts of oleum[448] at 100° gives the 4-sulfonic acid. 1,3-Diaminobenzene hydrochloride with five parts of oleum[448] at 170° likewise substitutes in the 4-position. With chlorosulfonic acid[409] the 4,6-disulfonyl chloride results. In contrast to this the 1,4-diamine is converted into its tetrachloro compound.

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[5] (*a*) Claus and Mann, *Ann.*, **265**, 94 (1891). (*b*) Suter and Weston, *J. Am. Chem. Soc.*, **62**, 604 (1940).

[6] Armstrong and Briggs, *Chem. News*, **65**, 138 (1892).

[7] Augustin and Post, *Ber.*, 8, 1561 (1875).

[8] Nölting, *Ber.*, 8, 1095 (1875).

[9] Kreis, *Ann.*, **286**, 381 (1895).

[10] Nölting and Kopp, *Ber.*, **38**, 3513 (1905).

[11] Badische Anilin- und Sodafabrik, German pat., 162, 635, *Chem. Zentr.*, II, 1142 (1905).

[12] Akt.-Ges. für Anilinfabrik, German pat., 172,461, *ibid.*, II, 479 (1906).

[13] Badische Anilin- und Sodafabrik, German pat., 175,378, *ibid.*, II, 1541 (1906).

[14] Post and Hardtung, *Ann.*, **205**, 96 (1880); Boyle, *J. Chem. Soc.*, **95**, 1708 (1909); Bayer and Co., German pat., 294,547, *Chem. Zentr.*, II, 780 (1916).

[15] Badische Anilin- und Sodafabrik, German pat., 132,968, *ibid.*, II, 315 (1902).

[16] Nietzki and Lerch, *Ber.*, **21**, 3222 (1888).

[17] Foth, *Ann.*, **230**, 300 (1885).

[18] Mayer, *Ber.*, **20**, 968 (1887).

[19] Scott, *J. Chem. Soc.*, **123**, 3191 (1923).

[20] Scott and Cohen, *ibid.*, **121**, 2034 (1922).

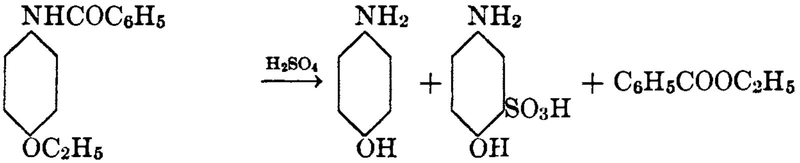
[21] Wagner, Kissling, Hotz, and Fitaky, U. S. pat., 1,815,747, *C.A.*, **25**, 5435 (1931); U. S. pat., 1,815,748, *C.A.*, **25**, 5435 (1931).

1,3-Diamino-4-chlorobenzene with oleum[449] gives the 6-sulfonic acid. This was not isolated as such, however, but as the acetyl derivative. 2,4-Diaminotoluene with oleum[450] sulfonates in the 5-position at 100°

Sulfonation of Aminophenols. Aminophenols and their ether and acyl derivatives, so long as the sulfonating agent is present in excess, undergo substitution *ortho* or *para* to the phenolic group regardless of the position of the basic substituent. On the other hand, in the "baking process" as applied to *p*-anisidine, *p*-phenetidine, and their chloro derivatives,[451] a sulfo group is introduced *ortho* to the nitrogen. These results support the suggestion already made (see p. 247) that the mechanism of sulfonation is not the same for the two reaction procedures. Since it was found by Cohn[452] that even 50% sulfuric acid readily forms a salt with phenacetin, sulfonation of weakly basic compounds *meta* to the nitrogen in the presence of excess acid is understandable. The difference between sulfonation and other substitution reactions has been noted in acet-*o*-anisidide[453] where sulfonation occurs *para* to the oxygen and chlorination and nitration *para* to nitrogen.

p-Aminophenolsulfonic acid and a number of its derivatives have been obtained by reducing nitrobenzene and its substitution products in concentrated sulfuric acid. Whether the reduction is performed electrolytically[454] or chemically[455] it is probable that a *p*-aminophenol is a necessary intermediate, this in turn coming from the rearrangement of an arylhydroxylamine.[456] A 10% yield of 4-aminophenol-2-sulfonic acid is obtained by heating nitrobenzene with sulfuric acid[457a] above 170°; here part of the nitrobenzene acts as a reducing agent for the remainder, *p*-aminophenol being an intermediate product. The reaction of phenyl azide with oleum[457b] also gives *p*-aminophenol-*o*-sulfonic acid when the reaction mixture is hydrolyzed.

4-Aminophenol is converted into the 2-sulfonic acid by warming with oleum[458] or sulfuric acid[452,459] a 92% yield resulting with the latter reagent. *p*-Anisidine if heated with sulfuric acid[459] at 100° is for the most part demethylated as well as sulfonated, but with 20% oleum at 55° a high yield of 4-aminoanisole-2-sulfonic acid results. *p*-Phenetidine has been similarly sulfonated.[460a] Phenacetin with sulfuric acid[452] at 100° sulfonates *ortho* to the ether group but with 80–90% acid under reflux the products are *p*-aminophenol, *p*-aminophenolsulfonic acid, and ethyl acetate. The benzoyl derivative behaves in an analogous manner.

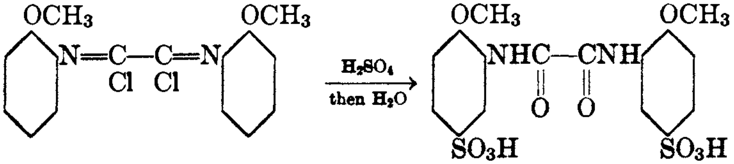


The urea derivative, $p\text{-}C_2H_5OC_6H_4NHCONH_2$, has also been sulfonated.[462] The sulfonation of a phenetidide derived from a high-molecular-weight fatty acid yields a cleaning agent.[460b] When acetaminophenyl acetate is treated with sulfuric acid the acetyl group on the oxygen is removed and sulfonation occurs *ortho* to hydroxyl.

p-Oxanisidide disulfonates[459] *ortho* to the methoxy groups when heated with sulfuric acid.

3-Aminophenol with three parts of sulfuric acid[461] at 100° gives the 6-sulfonic acid. The 4-sulfonic acid or the 4,6-disulfonic acid[462] treated similarly also is changed into the 6-sulfonic acid.

Sulfonation of 2-aminophenol with oleum[458] transforms it into the 4-sulfonic acid. The methyl ether with sulfuric acid[463] or oleum[453] gives a sulfonic acid of analogous structure, the oleum producing a 51% yield. Acet-*o*-anisidide with excess chlorosulfonic acid[453] at 50° is converted into the sulfonyl chloride in 75% yield. The corresponding acetoacetanisidide has been monosulfonated with 10% oleum,[464] but the position of the sulfo group was not determined. Sulfonation of the imino chloride obtained from ox-*o*-anisidide and phosphorus pentachloride gives a disulfonic acid which upon treatment with water loses the chlorines.[453]



4-Chloro-2-aminophenol and its N-acetyl derivative sulfonate at 100° with sulfuric acid[465] to the 6-sulfonic acids.

2,6-Dimethyl-4-aminophenol is quite possibly an intermediate in the preparation of the 3-sulfonic acid through the action of dilute sulfuric acid[466] upon 2,6-dimethylphenylhydroxylamine.

Sulfonation of tyrosine[467] and N-methyltyrosine[468] with sulfuric acid at 100° introduces a sulfo group *ortho* to hydroxyl in each instance. Methyl 3-hydroxy-4-aminobenzoate with oleum[469a] yields a sulfonic acid that probably has the 6-structure. 2-Hydroxy-5-aminobenzoic acid has been sulfonated by sulfuric acid.[469b]

SULFONATION OF BIPHENYL AND ITS DERIVATIVES

Compared with the numerous sulfonic acids which have been obtained from benzene and naphthalene and their derivatives the biphenyl series has been little investigated. Biphenyl has been readily available for only a few years and a convenient source of its alkyl derivatives is still lacking. It might be possible to remedy this deficiency as far as some of the methyl and ethyl compounds are concerned through the Friedel-Crafts reaction but this seems not to have been undertaken as yet. Until lately the sulfonic acids derived from benzidine were the only ones of importance technically, but it has now been shown [470,471] that other aminosulfonic acids synthesized from biphenyl produce excellent dyes.

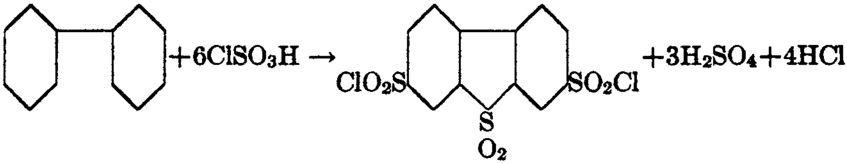
One characteristic of this hydrocarbon and some of its derivatives is their tendency to form 2,2′-cyclic sulfones when acted upon by sulfonating agents. Apparently only where groups such as hydroxyl make sulfonation possible under mild conditions does substitution occur in the 2-position without ring closure and sulfone formation.

The directive influence of one phenyl group when attached to another is not unlike that of a halogen. However, biphenyl sulfonates somewhat more readily than does chlorobenzene.

Sulfonation of Biphenyl. Several procedures for preparing biphenyl-4-sulfonic acid have been described. It results from heating biphenyl with an equal weight,[472] three times its weight,[473] or a 32% excess of sulfuric acid.[474] It may be separated from the disulfonic acid formed at the same time by the low solubility of its copper salt. A method which gives a higher yield (90%) than any of the foregoing consists in heating biphenyl in nitrobenzene with sulfuric acid.[475] This sulfonic acid also results from warming biphenyl with chlorosulfonic acid [476] in acetylene tetrachloride at 50°.

Biphenyl-4,4′-disulfonic acid is obtained in nearly quantitative yield by heating the hydrocarbon with excess sulfuric acid [470,473a,477a] and precipitating as the potassium salt with 20% potassium chloride. By an intermolecular sulfonation and desulfonation reaction, heating potassium biphenyl-4-sulfonate gives biphenyl and the 4,4′-disulfonate.[473b] The 4-sulfonyl chloride sulfonates in the 4′-position with 4% oleum without loss of the halogen.[477b]

If biphenyl is allowed to stand with an equal weight of chlorosulfonic acid for 12 hours at 18° or with a large excess at 0° an 80% yield of the 4,4′-disulfonyl chloride results. If, however, in the latter case the temperature is 18° the product is (xenylene-2,2′ sulfone)-disulfonyl chloride [(dibenzothiophenene dioxide)-2,7-disulfonyl chloride].[478]



Sulfonation of Alkylbiphenyls. The sulfonic acids of several homologs of biphenyl have recently been utilized[478] in separating these hydrocarbons from the high-boiling fractions of coal tar. 3-Methylbiphenyl apparently sulfonates in the 4-position while the 4-isomer gives a 2′-sulfonic acid. The proof of the structures is not, however, all that might be desired. A sulfonic acid was also obtained from 3,4′-dimethylbiphenyl. The pure hydrocarbons were regenerated from these sulfonic acids by high-temperature hydrolysis.

2,2′,3,3′,4,4′,6,6′-Octamethylbiphenyl with excess chlorosulfonic acid[479] at 0° gives a 77% yield of the disulfonyl chloride. 2-Methyl-5-isopropylbiphenyl with 6% oleum[480a] yields a sulfonic acid whose structure was not determined. The 9,10-dihydrophenanthrene may be regarded as a biphenyl derivative. By the action of sulfuric acid at 80° this is converted into a mixture of two disulfonic acids.[480b]

Sulfonation of Halo- and Nitrobiphenyls. 4,4′-Dibromobiphenyl with an equal weight of chlorosulfonic acid in chloroform[481] gives a mixture from which were separated a 32% yield of the 3-sulfonic acid and a 25% yield of the dibromobiphenylene-2,2′-sulfone. At 60° in the absence of a solvent the results were quite different. Some 41.5% of the mixture was the 3,3′-disulfonic acid, 12.5% the corresponding disulfonyl chloride, and 42% the sulfone mentioned above. With excess sulfuric acid at 80° the 3,3′-disulfonic acid was the only product isolated whereas 16% oleum at 80° gave also some of the sulfone; 30% oleum produced a disulfonic acid of the sulfone.

4-Nitrobiphenyl reacts readily with sulfuric acid[482] to give the 4′-sulfonic acid.

Sulfonation of Hydroxybiphenyls. Several sulfonic acids have been obtained from arylphenols. Slight warming of 4-hydroxybiphenyl with sulfuric acid[478a] gives chiefly a disulfonic acid in which one sulfo group must be in the 4′-position since a small amount of this monosulfonic acid accompanies the main product, separation being accomplished by the potassium salts. Heating the 4-hydroxybiphenyl-4′-sulfonate gives the disulfonate and 4-hydroxybiphenyl.

2-Hydroxybiphenyl sulfonates in the 5-position.[488a] Alkylated 2-hydroxybiphenylpolysulfonic acids and 4-hydroxybiphenylsulfonic acids have been patented as wetting agents.[488c, d]

2,2′-Dihydroxybiphenyl with sulfuric acid[483b] at 50–60° gives rise to the 5,5′-disulfonic acid while at 150° the 3,3′,5,5′-tetrasulfonic acid is formed. 3,3′-Dihydroxybiphenyl has been disulfonated but the structure of the resulting compound is uncertain.[484] 4,4′-Dihydroxybiphenyl is disulfonated when dissolved in sulfuric acid[485] at 100°, trisulfonated by heating with ten parts of the acid at 100–120°, and tetrasulfonated at 160–170°. The first two sulfo groups are in the 3,3′-positions and the others probably in the 5,5′-locations. With chlorosulfonic acid[486] 4,4′-diethoxybiphenyl yields the 3-sulfonic acid, the 3,3′-disulfonic acid, and a sulfonyl chloride.

Treating 3,3′,5,5′-tetrahydroxybiphenyl with cold sulfuric acid[487] converts it into a disulfonic acid of unknown structure.

A complex ketone, 2,2′,4,4′-tetramethyl-6,6′-di-(2-carboxybenzoyl)-biphenyl, is believed to sulfonate in the 3,3′-positions rather than in the benzoyl groups.[488]

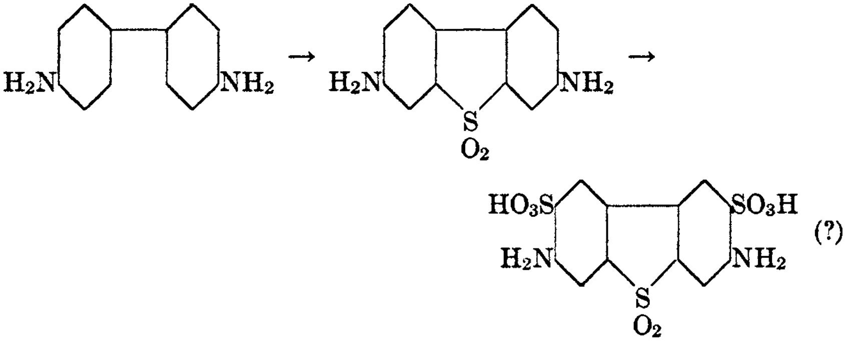
Sulfonation of Amino Derivatives of Biphenyl. The only biphenyl derivatives containing one or more amino groups which have been converted into sulfonic acids by direct sulfonation are, with the exception of 4-aminobiphenyl, all of the benzidine type. Undoubtedly further investigation of sulfonic acids in the biphenyl series would yield interesting and profitable results. Benzidine and its homologs under the proper conditions undergo ring closure with sulfone formation, a type of reaction already noted for other 4,4′-substituted biphenyl derivatives.

One sulfo group is introduced into 4-aminobiphenyl through the action of four parts of sulfuric acid[489a] at 130°. This is in the 4′-position since biphenyl itself sulfonates more readily than benzidine and hence the unsubstituted ring would react first. 4-Acetaminobiphenyl with chlorosulfonic acid gives the 4′-sulfonyl chloride.[489b]

Benzidine has been converted into a number of products by the action of sulfonating agents. By heating the acid sulfate[490, 491] at 170° for 24 hours or heating benzidine sulfate with six parts of 100% sulfuric acid at the same temperature, monosulfonation occurs in the 3-position. Baking the acid sulfate at 210–220° for 36–48 hours produces a 90% yield of the 3,3′-disulfonic acid. This is also the chief product when benzidine is heated with two parts of oleum[492] at 170°. It is interesting to note that azo dyes prepared from tetrazotized benzidine and β-naphthylamine sulfonate much more readily in the biphenyl nucleus than does benzidine itself.[490]

If benzidine is heated with a large excess of sulfuric acid at 180–190° it is converted into a mixture of the tri- and tetrasulfonic acids.[490, 493] Addition of oleum aids the reaction. The positions occupied by the last two sulfo groups are not known but judging from the reaction conditions they are probably *ortho* to the amino groups. Benzidine mono and disulfonic acids are practically insoluble in water while the tri and tetra compounds are readily soluble. Separation of the tri and tetra compounds is readily effected through their barium salts.

Sulfonation of benzidine with oleum below 100° yields the cyclic sulfone.[490] A 70% yield is obtained from 92 g. of benzidine and 800 g. of 21% oleum when the mixture is kept at 70–80° for 5 hours.[494] If the temperature is raised to 130–160° a mixture of the mono- and disulfonic acids of the sulfone is formed.[490]



3,3′-Dimethylbenzidine (tolidine) behaves in all respects like benzidine toward sulfonating agents.[490] By the action of oleum at 4° the 3,3′-dimethoxy- and 3,3′-diethoxybenzidine[495] are converted into the 6,6′-disulfonic acids, apparently without sulfone formation occurring.

N,N,N′,N′-Tetramethylbenzidine is converted into the 3-sulfonic acid by treatment with 12% oleum.[496] Benzidine-2,2′-disulfonic acid, prepared by the benzidine rearrangement is readily sulfonated by oleum[497] to a tetrasulfonic acid of uncertain structure.

Sulfonation of Diphenylmethane and Its Derivatives

The directive influence of the benzyl group differs from that of methyl in that no *ortho* sulfonation products have been reported. Thus diphenylmethane upon treatment with chlorosulfonic acid[498] at 0° in chloroform gives the 4-sulfonic acid, and excess oleum[499] at 100° results in the formation of the 4,4′-disulfonic acid. The mono-[480] and disulfonic acids[500] obtained from 2-methyl-5-isopropyldiphenylmethane, and two sulfonic acids from[501] 4-methyldiphenylmethane are of unknown structure. 4-Hydroxydiphenylmethane with a slight excess of sulfuric acid at 100° sulfonates in the 3-position[502] while with 1.5

parts of this reagent a disulfonic acid is formed.[503] What is probably 2-hydroxydiphenylmethane has also been sulfonated.[504] All three nitrodiphenylmethanes give the 4′-sulfonic acid when heated with sulfuric acid.[505] The action of 23% oleum [506] at 130° upon 3,3′-dimethyl-4,4′-diaminodiphenylmethane converts it into a disulfonic acid. Adding 25% oleum [507a] to a solution of 4,4′-bis-(dimethylamino)-diphenylmethane in 100% sulfuric acid at 110° gives the 2- or 3-sulfonic acid. 2-Hydroxy-4-diethylamino-2-carboxydiphenylmethane undergoes both sulfonation and ring closure when treated with 30% oleum [507b] at 100°.

Sulfonation of Benzophenone and Its Derivatives

Like the benzyl group, the benzoyl substituent directs sulfonation to a single position, in this case the *meta*. Apparently benzophenone has not been monosulfonated, ten parts of 15% oleum [400b, 508] at 90° converting it into the 3,3′-disulfonic acid. 2,4-Dimethylbenzophenone with 20% oleum [509] substitutes in the 5-position. The sulfonation products of 2,5-dimethylbenzophenone,[510] 2,4,6-trimethylbenzophenone,[510] and 2-methyl-5-isopropylbenzophenone [511] are of unknown structure. 4-Phenyl-2′-carboxybenzophenone is sulfonated by sulfuric acid,[512] probably in the phenyl group.

Two nitro compounds, the 3-nitro-4′-methylbenzophenone [513] and the 3-nitro-2′,4′-dimethyl compound [514] sulfonate slowly with oleum, the sulfo groups undoubtedly entering the ring having the alkyl groups; the positions have not been determined, however.

4-Methyl-3′-aminobenzophenone reacts with oleum [513] at 100° to produce a monosulfonic acid. 4-Dimethylaminobenzophenone with the same reagent at 130° is converted into the 3-sulfonic acid.

Sulfonation of Miscellaneous Diaryl Compounds

Sulfonation of Diarylalkanes. The next higher homolog of diphenylmethane, 1,2-diphenylethane (dibenzyl), reacts with two volumes of sulfuric acid [515] to form a disulfonic acid, probably with the 4,4′-structure, and a trace of a tetrasulfonic acid. One might expect more of a trisulfonic acid than of the tetra compound but this was not reported. 1,1-Diphenyl-2,2,3-trichlorobutane with oleum [516] yields a disulfonic acid of unknown structure.

Sulfonation of Diarylalkenes. Several sulfonic acids of the 1,2-diphenylethylene or stilbene type have been prepared by sulfonation reactions. The most important methods for preparing these compounds, however, involve other procedures.

A disulfonic acid results from the action of oleum[517] on stilbene. It is noteworthy that the ethylene linkage is apparently unaffected. 2,4-Dinitrostilbene with ten parts of sulfuric acid at 100° gives a monosulfonic acid and with oleum at the same temperature a disulfonated compound.[518] 2,4-Dinitro-α-(or β)-chlorostilbene is converted into the 4′-sulfonic acid when sulfonated.

A compound differing from the stilbene type in that both aryls are attached to the same carbon, namely α,α-bis-(2,4,5-trimethylphenyl)-β,β-dichloroethylene, with 20% oleum[519] yields a disulfonic acid which may be either the 3,3′- or 6,6′-derivative.

Sulfonation of Some Ketones and Acids. A number of more complex diaryl compounds have been sulfonated. The sulfonation of a series of alkyldesoxybenzoins of the general formula $C_6H_5CHRCOC_6H_5$ where R contains sixteen to eighteen carbons yields wetting agents.[520a] Also several chalcones[520b] containing one or two methoxy groups, and their dihydro compounds; the truxillic acids,[521] 2-hydroxybenzal-α-indanone,[522a] the isatropic acids[522b] and podocarpic acid[522c] have all been converted into sulfonic acids.

Sulfonation of Aryl Ethers, Sulfides, and Sulfones. Ethers and sulfides behave similarly toward sulfonation except that an *ortho* sulfonic acid is not formed in the ether series when a *para* position is vacant. In the sulfonation of phenyl sulfide the 2,2′- and 4,4′-disulfonic acids are produced. The available data are presented in Table XII. Here *A* represents sulfuric acid, *B*, oleum, and *C*, chlorosulfonic acid.

The sulfonation of a number of other sulfones is mentioned incidental to reactions in which sulfonic acids are the principal products.

A large number of alkylated phenyl ether sulfonic acids have been described as wetting agents or detergents.[523]

$$RC_6H_4OC_6H_5 + H_2SO_4 \rightarrow RC_6H_4OC_6H_4SO_3H + H_2O$$

Sulfonation of Diphenylamine and Its Derivatives. The majority of the sulfonic acids related to diphenylamine have been made by the condensation of an aromatic amine with a halogen compound in which the halogen is activated by the presence of the nitro or carboxy group. Only for diphenylamine itself have the effects of sulfonating agents been investigated in detail.

Diphenylamine is little affected by sulfuric acid at 100°, but at 150–170° five parts of the amine with six parts of acid[524a] give a mixture of mono- and disulfonic acids together with unchanged amine. With chlorosulfonic acid[524b] in nitrobenzene below 90° it is possible to get the addition product $(C_6H_5)_2NH_2OSO_2Cl$ which decomposes at higher

TABLE XII

Compound Sulfonated	Reagent and Reference	Reaction Data	Position(s) of Sulfo Group(s)
Phenyl ether substituents			
None	NH_2SO_3H,[1] 1 mole	....	4-
	A,[2, 17] 1.2 mole	In acetic anhydride, 100°	4- (93% yield)
	A,[3] excess	100°	4,4′-
	C,[2] 2.2 parts	25–30°	4,4′-di-SO_2Cl (88% yield)
4-Bromo-	*A*,[2] 2 moles	100°	4- (100% yield)
	C,[2] 2.2 moles	25–30°	4-SO_2Cl (45%)
2-Nitro-	*A*[4]	100°	4′- (?)
4-Nitro-	*B*[4]	100°	4′- (?)
2,4-Dinitro-	*A*[5]	Warming	4′- (?)
2,4-Dinitro-6-carboxy-	*A*[6]	150°	4′- (?)
4-Amino-	*A*[7], 1 mole	180°	3- (?)
Miscellaneous compounds			
1,2-Diphenoxyethane	*A*[8]	....	4,4′-di
ω-Phenoxyacetophenone	*A*[9]	....	?
1,3-Diphenoxy-2-hydroxypropane	*A*[10]	Warm	4,4′- (?)
β-Phenoxy-β-phenylpropionic acid	*A*[16]	130–135°, 1 min.	4,4′- (?)
Phenyl sulfide	*A*[11]	15°	2,2′- and 4,4′-
	A,[12] 3 parts	100°, 12 hrs.	4,4′-
	C,[12] 1 mole	....	4- (?)
	C,[13] 2 moles	....	4,4′-
Phenyl sulfone	*C*,[14] 1 mole	150°	3-
	C,[15] 2 moles	150–160°	3,3′-

---

[1] Quilico, *Atti. accad. Lincei*, [6] **6**, 512 (1927).

[2] Suter, *J. Am. Chem. Soc.*, **53**, 1112 (1931).

[3] Fittig, *Ann.*, **125**, 330 (1863); Hoffmeister, *Ber.*, **3**, 747 (1870); *Ann.*, **159**, 191 (1871).

[4] Jones and Cook, *J. Am. Chem. Soc.*, **38**, 1538 (1916).

[5] Cook, *ibid.*, **32**, 1292 (1910).

[6] Purgotti, *Gazz. chim. ital.*, **44**, I, 642 (1914).

[7] A.-G. für Anilinfabrik, German pat., 169,357, *Chem. Zentr.*, I, 1307 (1906).

[8] Lippmann, *Compt. rend.*, **68**, 1271 (1869).

[9] Stoermer and Atenstädt, *Ber.*, **35**, 3564 (1902).

[10] Rössing, *Ber.*, **19**, 66 (1886).

[11] Bourgeois and Petermann, *Rec. trav. chim.*, **22**, 350 (1903).

[12] Otto and Tröger, *Ber.*, **26**, 994 (1893).

[13] Otto and Knoll, *Ber.*, **11**, 2075 (1878); Otto, *Ber.*, **19**, 2418 (1886).

[14] Otto and Rössing, *Ber.*, **19**, 3125 (1886).

[15] Zehenter, *Monatsh.*, **37**, 598 (1916).

[16] Bogert and Marcus, *J. Am. Chem. Soc.*, **41**, 103 (1919).

[17] Voroshtsov, *J. Gen. Chem.* (*U.S.S.R.*), **10**, 935 (1940); *C.A.*, **35**, 3989 (1941).

temperatures with evolution of hydrogen chloride and formation of a sulfonic acid. The products vary with the amount of chlorosulfonic acid used as shown in Table XIII. From this it is seen that the use of 0.5 molecular equivalents of sulfonating agent is the most efficient for preparing the monosulfonic acid. Substitution occurs in the 4-position as the trinitrated sulfonic acid is the same as the compound obtained from picryl chloride and sulfanilic acid. Disulfonation to the 4,4′-compound is readily carried out at 110–115°.

TABLE XIII

SULFONATION OF DIPHENYLAMINE

MOL. EQ. OF $ClSO_3H$	UNCHANGED AMINE, %	MONOSULFONIC ACID, %	DISULFONIC ACID, %
0.5	70	25	5
1.0	40	38	22
1.5	16	34	50
2.0	0	0	100

A by-product obtained in small yield from the action of methyl sulfate [525] upon diphenylamine is probably diphenylmethylamine-4-sulfonic acid. Diphenylmethylamine with 0.54 part of sulfuric acid [526] at 160° for 10 hours produces a sulfonic acid of unknown structure, while the reaction with oleum was reported to proceed with difficulty.

Acetyldiphenylamine with oleum [527] at 45° gives a monosulfonic acid, whereas at 120° disulfonation occurs.

3-Hydroxydiphenylamine with sulfuric acid [528] at 100° is converted into the 4-sulfonic acid and the 4-hydroxy compound with the same reagent in the cold [529] yields the 3-sulfonic acid. The sulfonation product obtained from 4-aminodiphenylamine is of uncertain structure.[530]

Sulfonation of Benzylarylamines. In the sulfonation of compounds containing phenyl and benzyl groups attached to nitrogen, substitution occurs first in the benzyl part of the molecule. Salt formation with the amine decreases the ease of sulfonation in the ring directly attached to the amino group. Thus phenylbenzylmethylamine with 100% sulfuric acid at 100° monosulfonates in the benzyl group [531] while with oleum [532] disulfonation results, the second sulfo group going *meta* in the ring attached to nitrogen. Phenylbenzylethylamine behaves in an exactly analogous manner. Among the products obtained by the action of thionyl chloride [533] in ether solution upon these two amines are the monosulfonic acids which were separated after boiling the reaction mixtures with water.

o-Tolylbenzylamine with 100% sulfuric acid[534] and *m*-tolylbenzylethylamine with 20% oleum[535] are converted into sulfonic acids whose structures are unknown. The sulfonation probably occurs in the benzyl groups. Dibenzylamine with oleum[536] yields the 4,4′-disulfonic acid. It is interesting to note that benzalaniline in contrast to the benzyl compounds sulfonates in the ring attached to nitrogen.[537]

Sulfonation of Azobenzene. The action of 20% oleum upon azobenzene[538] at 20–80° gives a 90% yield of a sulfonic acid whose properties differ from that obtained by indirect methods. The compounds are believed to be *cis-trans* isomers.

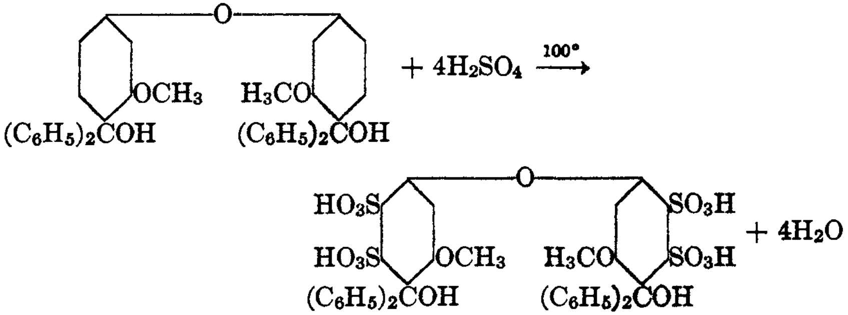
Sulfonation of Tri- and Tetraaryl Compounds

Sulfonation of Triphenylmethane and Its Derivatives. With few exceptions the triphenylmethane derivatives that have been sulfonated are amines which are the leuco compounds of dyes. These are presented in tabular form.

Triphenylmethane with oleum[539a] yields a trisulfonic acid of unknown structure. 2-Methoxytriphenylacetic acid when shaken with sulfuric acid[539b] is converted into 2-methoxy-4(or 5?)-sulfotriphenylcarbinol. The 2,4-dimethoxy compound behaves similarly. It is claimed that the methyl ester of this latter acid gives a 6-sulfonic acid, but this is contrary to what would be expected.

$$[(C_6H_5)_2CC_6H_3(OCH_3)_2]COOCH_3 + H_2SO_4 \rightarrow [(C_6H_5)_2CC_6H_2(OCH_3)_2SO_3H]COOCH_3 + H_2O$$

The lactone of 2,4-dihydroxytriphenylacetic acid is sulfonated in the 5-position and hydrated to the free acid through the action of excess sulfuric acid.[539] The complex triphenylcarbinol ether shown in the equation undergoes tetrasulfonation, supposedly in the positions indicated.



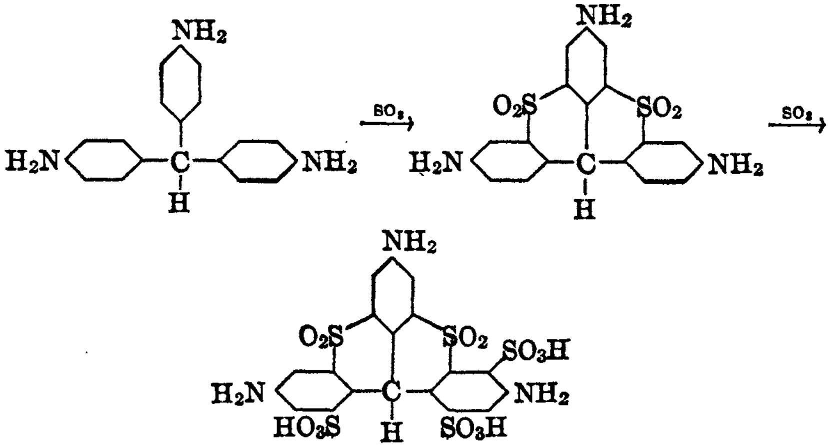
This structure for the sulfonic acid is quite unlikely as *ortho* disulfonation is extremely rare.

A number of compounds related to 4,4′-bis-(dimethylamino)-triphenylmethane have been converted into sulfonic acids. In the first column of Table XIV is shown the substituent, if any, in the third benzene ring. *A*, *B*, and *C* represent sulfuric acid, oleum, and chlorosulfonic acid respectively (see p. 268).

4,4′-Bis-(diethylamino)-3″-hydroxytriphenylmethane upon treatment with oleum yields the 4″,6″-disulfonic acid.[540] The analogous 4,4′-bis-(benzylethylamino)-3″-hydroxytriphenylmethane sulfonates similarly. 4,4′-Bis-(benzylmethylamino)-triphenylmethane and its ethyl analog when trisulfonated[541] substitute in the *para* positions in the two benzyl groups and in the unsubstituted phenyl. Monosulfonation of 4,4′-bis-(benzylethylamino)-2″-sulfo-5″-nitrotriphenylmethane also occurs in one of the benzyl groups.[542]

Di-(benzalhydrazino)-triphenylmethane with oleum[543] undergoes both sulfonation and oxidation with formation of a green dye.

4,4′,4″-Triaminotriphenylmethane with 60% oleum[544] at room temperature gives a disulfone which by heating with the sulfonating agent is trisulfonated. These reactions are shown below.



Sulfonation of Other Triaryl Compounds. Triphenylamine when acted upon by excess oleum[545] below 60° is trisulfonated, most likely in the *para* positions. Dibenzylphenylamine with oleum[531b] at 80° sulfonates in the benzyl groups in the *para* positions.

4-Hydroxydiphenylbenzoylmethane monosulfonates readily.[546] The sulfo group undoubtedly occupies the 3-position. Phenylbenzylben-

TABLE XIV

SULFONATION OF 4,4′-BIS(DIMETHYLAMINO)-TRIPHENYLMETHANES

Group in Third Ring	Reagent and Reference	Reaction Data	Position of Sulfo Group
None	*A* or *B*[1]	"Heat"	4″-
2″-Methyl-	*B*,[2] 25%	....	4″- (?)
2″-Methyl-5″-sulfo-	*B*[3]	....	3″-
4″-Methyl-	*B*,[2] 25%	....	3″-
2″-Chloro-	*C*[2]	In $CHCl_3$, warm	(?)
2″-Methoxy-	*B*,[2] 25%	100°	5″- (?)
4″-Methoxy-	*B*,[2] 25%	100°	3″- (?)

[1] Döbner, *Ann.*, **217**, 259 (1883).

[2] Nölting and Gerlinger, *Ber.*, **39**, 2048 (1906).

[3] Leonhart and Co., German pat., 128,086, *Chem. Zentr.*, I, 447 (1902).

zoylmethane has also been sulfonated [547] but the position of the entering group is here more difficult to predict.

Sulfonation of Tetraphenyl Compounds. *sym*-Tetraphenylethane [548] and tetraphenylethylene [549] with warm sulfuric acid yield tetrasulfonic acids. Phenylaminotriphenylmethane with pyrosulfuric acid [550] below 60° sulfonates in the ring attached to nitrogen, probably in the *para* position.

SULFONATION OF NAPHTHALENE AND ITS ALKYL DERIVATIVES

The naphthalenesulfonic acids are valuable as sources of the naphthols, naphtholsulfonic acids, and nitronaphthalenesulfonic acids; these last are utilized in the preparation of the corresponding amino compounds, useful as dye intermediates. In contrast to the benzene series the homologs of naphthalene have been little investigated, the hydroxy and aminonaphthalenesulfonic acids having received the greater share of the attention.

Sulfonation of Naphthalene. The reactions of naphthalene with various sulfonating agents have been studied by numerous investigators over a period of more than one hundred years. Brande [551] was apparently the first to report the formation of water-soluble acidic products through the action of sulfuric acid. Faraday [552a] was aware that two sulfonic acids were produced and was able to separate them through their barium salts. He also noticed that the acid present in smaller amount diminished in importance at low temperatures of sulfonation, but it was not until much later [553] that the effect of temperature in determining the ratio between the yields of the two isomers was examined in any detail and satisfactory methods for separating the two compounds developed.

In the course of their extensive investigations of the sulfonation of naphthalene Armstrong and Wynne [554a] came to the conclusion that regardless of the experimental conditions there were certain limitations upon the position which a sulfo group would assume when one or more other such groups were already present. No sulfonic acid could be prepared by direct methods in which two sulfo groups were *ortho, para,* or *peri* to each other. This rule limits the sulfonation products to those shown in the chart. Here *S* represents SO_3H.

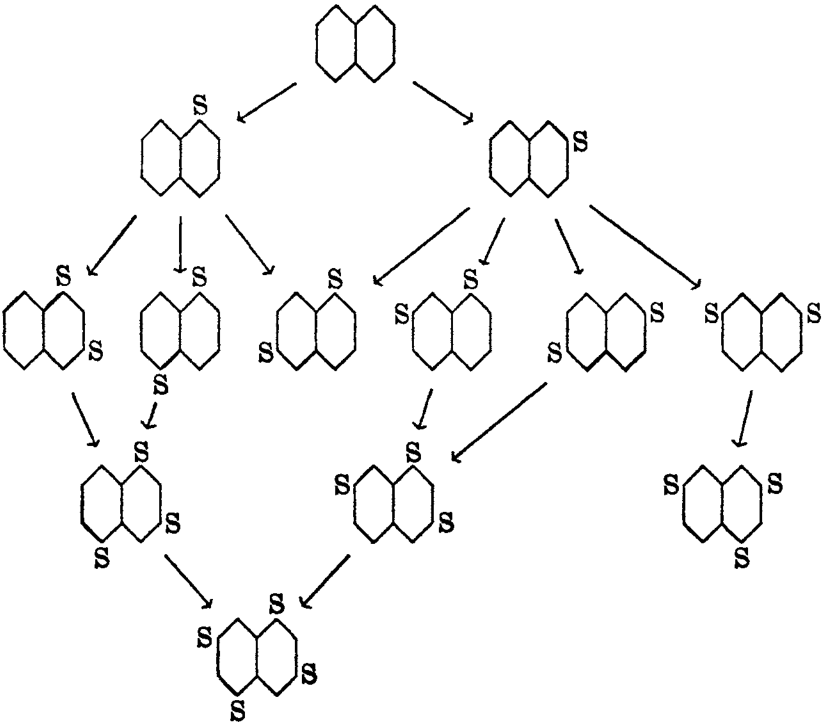


CHART I

Of the various predicted acids the 1,3-disulfonic acid has been made only recently by a sulfonation reaction. It has been found that the 1,3,6-trisulfonic acid is actually a final sulfonation product since it is not affected by sulfur trioxide whereas the other two trisulfonic acids are converted into the 1,3,5,7-tetrasulfonic acid. Out of a theoretically possible seventy-five naphthalenesulfonic acids, twelve are obtainable through sulfonation reactions. However, if only the acids containing up to and including four sulfo groups are included there are forty-eight possibilities: two mono, ten di, fourteen tri, and twenty-two tetrasulfonic acids.

The historical aspect of the sulfonation of naphthalene has already been outlined. Both the temperature and the time of heating have an effect on the ratio of the 1-sulfonic acid to the 2-isomer when the hydrocarbon is heated with sulfuric acid. This is brought out in the tables taken from the work of Euwes.[585] These results amplified the work of previous investigators.[553b] In Table XV reaction mixtures containing 5 g. of naphthalene and an equimolecular amount of sulfuric acid were heated at various temperatures for 8 hours and the products determined.

TABLE XV

SULFONATION OF NAPHTHALENE

t, °C.	$C_{10}H_8$ RECOVERED, %	1-SULFONIC ACID, %	SULFONES, %	DISULFONIC ACIDS, %
80	27	96.4	....	....
90	23.2	89.8	....	....
100	20	83.2	....	....
110.5	15.4	72.6	....	....
124	11.2	52.4	....	....
129	10	44.4	1.02	....
138.5	8.6	28.4	....	....
150	6.4	18.3	3.2	....
161	6.0	18.4	5.5	....
168	....	23.2	....	7
173	....	26.5	10.5	19

The reaction product not included in the table is the 2-sulfonic acid. The influence of varying the reaction time is shown in Table XVI. Here the temperature was 129°. It was concluded that 8 hours was sufficient to bring about equilibrium between the two acids but further experiments showed this to be true only above 140°. At 129° equilibrium was approximated only after 42 hours, 23% of the 1-sulfonic acid then remaining. Heating the 1-sulfonic acid at 129° with an equimolecular amount of sulfuric acid for 7 hours converted 47% of it into the 2-isomer while heating naphthalene with two molecular equivalents of sulfuric acid gave 48.4% of this isomer. If the sulfonation is carried out at 0° only about 2% of the 2-sulfonic acid is formed[556] whereas at 40° it was estimated[557] at about 4%.

TABLE XVI

TIME, HOURS	1-SULFONIC ACID, %
0.58	79.1
1	72.9
2	61.7
4	50.0
6	45.1

The effect of the concentration of the sulfuric acid upon the production of the two monosulfonic acids formed is shown in Table XVII.

TABLE XVII

	1-SULFONIC ACID, %		NAPHTHALENE
ACID USED	Time, 2 hrs.	Time, 7–8 hrs.	RECOVERED, %
12% oleum	69.8	62.1	(sulfones and di-acids)
100% sulfuric	61.7	44.4	10
96% sulfuric	46.7	44.4	23
90% sulfuric	....	44.6	32

Here the reaction temperature was 129°. Adding phosphorus pentoxide to the mixture resulted in more sulfone formation.[555]

In a recent discussion [10b, 558a] of the equilibrium existing between the 1- and 2-sulfonic acids it was reported that prolonged heating of the reaction mixture at 100° reduced the percentage of the 1-isomer from the 80 usually given as the "equilibrium" value to 29.3, and a mathematical analysis of the reaction data indicated that if equilibrium were actually attained only 22.6% would be present. The ratio of any two acids at equilibrium is equal to the ratio of the velocity coefficients of their formation divided by the ratio of the coefficients of their hydrolysis, or

$$\frac{[\alpha]}{[\beta]} = \frac{k_\alpha/k_\beta}{k_\alpha^h/k_\beta^h}$$

From this, if a mixture of two unequally hydrolyzed isomers is initially produced in a sulfonation, their ratio will vary with time, the yield of the more easily hydrolyzed product gradually being decreased until equilibrium is established. In general, the compound more easily formed by sulfonation is also the more rapidly hydrolyzed so that the compound predominating after a short reaction time will be reduced in amount after prolonged heating. It seems unnecessary to assume any direct conversion of one isomer into the other, this apparently always occurring through hydrolysis as an intermediate stage.[558b] It has been pointed out [558c] that the situation is more complex than Ioffe suggested in that the sulfonation equilibrium constants depend upon the state of equilibrium between sulfuric acid and its hydrates.

A very satisfactory procedure for obtaining the 1-sulfonic acid on a small scale calls for the addition of 128 g. of naphthalene to 260 g. of 100% sulfuric acid [559] at 0°; after standing for an hour the reaction mixture is poured into water. The dihydrate crystallizes from the water solution when the density is about 1.29–1.30 and the temperature is kept at 0°. The acid is readily recrystallized from 20% hydrochloric acid, the dihydrate melting at 90°. Preparation of the pure naphthalene-2-sulfonic acid has also been described in detail.[560] Here the requirements are 250 g. of naphthalene and 400 g. of 94% sulfuric acid which are kept at 160° for 5 minutes and then poured into 300 ml. of water. Cooling gives an 80% yield of the trihydrate contaminated by 2 g. of the 2,2′-sulfone. The reaction mixture under these conditions contains 15% of the 1-sulfonic acid.[557] Purification of the 2-isomer is best effected by crystallizing from hydrochloric acid as with the 1-compound. The trihydrate melts at 83° and the monohydrate at 124°. Separation of the 2-sulfonic acid from the sulfonation mixture by extraction with toluene has been patented.[561] The sodium salt may be obtained conveniently by neutralizing a sulfonation mixture with enough sodium carbonate or hydroxide [562] to account for the sulfonic acid and enough lime to precipitate the sulfuric acid as calcium sulfate.

In the sulfonation of naphthalene on a commercial scale the use of an excess of sulfuric acid may be avoided by heating with the theoretical amount of 93% acid at 155° under a pressure reduced to 600 mm.[563] which removes the water formed in the reaction, or by passing benzine or carbon tetrachloride vapors through the mixture [14, 564a] until all but 3–4% of the acid is utilized. Addition to the sulfonation mixture of some more easily sulfonated compound has also been suggested.[564b]

In addition to the sulfuric acid method, naphthalene has been monosulfonated with 15% oleum [565] which below 70° gives chiefly the 1-sulfonic acid as does sodium trihydrogen disulfate [86] at 100°. At 180° this acid salt yields chiefly the 2-isomer. Adding slightly less than the calculated amount of chlorosulfonic acid [566] to a 10% solution of naphthalene in carbon disulfide produces the 1-sulfonic acid and a little 1,5-disulfonic acid but no 2-sulfonic acid. The presence of the 1,5-disulfonic acid in the commercial 1-sulfonic acid has been commented upon [567] more recently. Naphthalene has also been monosulfonated by the action of pyridine sulfotrioxide.[288, 568] By the action of 400 g.

of fluorosulfonic acid [27a] upon 250 g. of naphthalene dissolved in 600 g. of sulfuric acid 65 g. of the 1-sulfonyl fluoride results.

In addition to the methods of separating the two sulfonic acids already described it has been found possible to precipitate the 2-sulfonic acid as its ferrous salt.[569] The 2-sulfonic acid may be freed from the 1-isomer by hydrolysis [570] of the latter at 145–155°, only a trace [570b] of the 2-acid being affected.

A satisfactory method for the analysis of the mixture obtained in the high-temperature sulfonation procedure has been described [571] in detail. In this procedure the insolubility of the benzidine salts of the 2-sulfonic acid and the 2,6- and 2,7-disulfonic acids together with the low solubility of sodium 2-naphthalenesulfonate in a sodium chloride solution are utilized.

Disulfonation of Naphthalene. Disulfonation of naphthalene at not above 40° by dissolving 128 g. of the hydrocarbon in 300 g. of 100% sulfuric acid and then adding 300 g. of 64% oleum [572] gives about 70% of the 1,5-disulfonic acid and 25% of the 1,6-isomer. At temperatures above 40° the 1,5-acid decreases until at 130° it has almost disappeared, the products then being chiefly the 1,6- and 2,7-compounds.[573] Recently [574] small amounts of the 1,7- and the 1,3-isomers have also been isolated in the form of their acid chlorides. The 1,7-compound arises from the further sulfonation of the 2-sulfonic acid; at a low temperature 20% of this is converted into the 1,7-disulfonic acid and the other 80% into the 1,6-compound.[575] Above 140° the 2,6-disulfonic acid appears [572a, 576] but is never produced in more than 30% yield, although heating the 2,7-disulfonic acid at 160° with 95% sulfuric acid transforms 42% of it into this isomer.[577] The best yield of the 2,6-acid obtained directly from naphthalene [572a] results from the use of a large excess of 100% sulfuric acid at 180°. Under these conditions there were isolated 27% of the 2,6-compound, 65% of the 2,7-, and 10% of the 1,6-disulfonic acid.[576b] The relation of the 2,6-acid to the other two is curious in that at 100° as much as 30% of the 1,5-compound is transformed into this by heating with sulfuric acid while at 130° neither the 1,5- nor the 2,6-acid is present; this 2,6-compound, however, reappears in the reaction mixture to the extent of 20% at 160°. Conversion of the 2,7- to the 2,6-isomer has already been mentioned; the reaction is reversible, 13% of the latter going over to the former by 8 hours' heating with sulfuric acid at 160°. Quantitative estimation of the varying amounts of the acids in a mixture is accomplished by making use of the different solubilities of the calcium,[578] barium, and lead [579] salts.

From the commercial standpoint the disulfonation reaction should lead to as high a yield as possible of the 2,7-disulfonic acid. A continuous vapor-phase process for obtaining 78–85% yields of this compound at a temperature of 220–245° by the action of 80–95% sulfuric acid has been described in detail.[580a] The action of 4% oleum upon 2-naphthalenesulfonyl chloride at 15–20° brings about sulfonation without hydrolysis of the chloride group.[580b] Pure compounds were not isolated.

Treatment of naphthalene with two molecular equivalents of chlorosulfonic acid [566,581] at 15–45° gives besides the 1,5-disulfonic acid appreciable quantities of the disulfonyl chloride. If carbon tetrachloride is used as a solvent some of the sulfonyl chloride results even when the naphthalene is present in excess. Low temperatures favor sulfonyl chloride formation since at 150–155° trisulfonation [582] to the 1,3,6-compound occurs. If the potassium naphthalene-2-sulfonate is treated with three molecular equivalents of chlorosulfonic acid [581b] at 100° the 1,6-disulfonic acid results. By dissolving 200 g. of naphthalene in 2 kg. of chlorosulfonic acid [476] at 0° there is obtained 300 g. of the 1,5-disulfonyl chloride, m.p. 183°. This is undoubtedly the simplest method of preparing this compound.

From 25 g. of naphthalene and 100 g. of fluorosulfonic acid [27a] at 75° a disulfonyl fluoride, m.p. 125°, is formed. This is not the 1,5-compound which melts at 203°. The disulfonyl chloride obtained from the fluoride melted at 118°. Further sulfonation of the 1-sulfonyl fluoride with fluorosulfonic acid yields a mixture from which some of the 1,5-disulfonyl fluoride was isolated. With chlorosulfonic acid the 1-sulfonyl fluoride, 5-sulfonyl chloride was obtained. If, however, the 2-sulfonyl fluoride is the starting product the 2,6-compound results.

Tri- and Tetrasulfonation of Naphthalene. Three trisulfonation products of naphthalene are known. By dissolving sodium 1,5-naphthalenedisulfonate in 100% sulfuric acid and then adding 67% oleum [583] with final warming to 90° the 1,3,5-trisulfonic acid is formed. The 1,3,6-acid is the principal product obtained by sulfonating naphthalene with excess 24% oleum at 180° or with 40% oleum [584] at 100°. The other trisulfonic acid, the 1,3,7-isomer, results from the reaction of the 2,6-disulfonic acid with oleum [585] at 100°. The 1,3,5- and 1,3,7-trisulfonic acids sulfonate further with oleum [586] to the 1,3,5,7-tetrasulfonic acid. Contrary to earlier reports [587] a second tetrasulfonic acid is not formed when phosphorus pentoxide is added and the reaction mixture heated to 260°; the error was made because the barium 1,3,5,7-tetrasulfonate exists in two crystalline forms.

Sulfonation of the Alkylnaphthalenes. In marked contrast to the intensive study which the sulfonation reactions of naphthalene have received, investigation of the behavior of the alkylnaphthalenes has barely begun. The formation of sulfonic acids from 1-methyl-,[588] 2-methyl-,[589] 1-ethyl-,[588] 2-ethyl-,[590] and an isopropylnaphthalene[591] had been reported without information as to the structures of the products being obtained. Comparatively recently it was shown that 1-methylnaphthalene with sulfuric acid at room temperature for 5–6 hours[592] gives a good yield of the 4-sulfonic acid; at 110° a mixture[593a] of the 3- and 7-isomers is formed in which the 3-compound predominates, while at 165–170° after 5-6 hours[594] the 7-sulfonic acid becomes of primary importance. With chlorosulfonic acid in the cold[593] a mixture of the 4- and 5-sulfonic acids is formed, 319 g. of the hydrocarbon giving rise to 370 g. of potassium 1-methylnaphthalene-4-sulfonate and 75 g. of a mixture of isomeric salts.[595]

Heating 2-methylnaphthalene with sulfuric acid[596a] at 90–100° gives an 80% yield of the 6-sulfonic acid. No other isomers were isolated. With chlorosulfonic acid in nitrobenzene[596b] at 30–40° the 8-sulfonic acid results. 2-Ethylnaphthalene when heated with 66% sulfuric acid[596c] gives the 6-sulfonic acid in 86% yield. The barium salt is only slightly soluble in water.

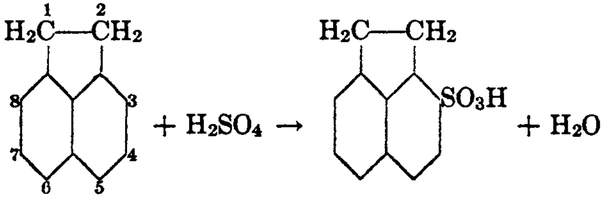
By sulfonation of a coal-tar fraction of hydrocarbons, boiling at 260–365°, with 0.6 part of sulfuric acid[597] at 40–45° for 10 hours and conversion of the resulting sulfonic acid to the sodium salt there was obtained some sodium 1,6-dimethylnaphthalene-4-sulfonate. When the same hydrocarbon mixture was sulfonated with an equal weight of 98% sulfuric acid at 135–140° for 3 hours, 2,6-dimethylnaphthalene-7-sulfonic acid was isolated. At 35–40°, however, 2,6-dimethylnaphthalene yields almost entirely the 8-sulfonic acid which rearranges to the 7-isomer when heated with 78% sulfuric acid at 135°. Low-temperature sulfonation probably also yields some 2,6-dimethylnaphthalene-1-sulfonic acid but this was not identified with certainty. A mixture of two or more sulfonic acids of 2,7-dimethylnaphthalene was also isolated. One of these acids, the 3-isomer, was obtained in a pure condition. In one experiment a small yield of a sulfonic acid of 2,3-dimethylnaphthalene[598a] was separated from some crude 2,6-dimethylnaphthalene-7-sulfonic acid. The 2,6-dimethylnaphthalenesulfonic acids have been described further in a more recent patent.[598b]

A sulfonic acid of unknown structure has been obtained from 1,4-dimethylnaphthalene.[599] Ethylisopropylnaphthalenesulfonic acids are claimed to be present in the product obtained by the action of chlorosulfonic acid upon naphthalene mixed with ethyl and isopropyl alcohols,[600] and other alkylated naphthalenesulfonic acids are produced in the reaction mixture resulting from the action of either chlorosulfonic acid or oleum upon naphthalene mixed with methyl or ethyl alcohols or a mixture of the two with higher-molecular-weight alcohols.[601a] In a procedure employed for butylating and sulfonating aromatic compounds naphthalene was mentioned in one example.[601b] In other processes the condensation of an unsaturated hydrocarbon or alcohol with naphthalene occurs after the sulfonation.[601c]

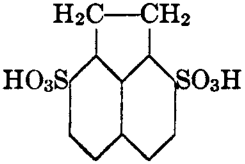
The sulfonation of 1-benzylnaphthalene may also be mentioned here. With either warm sulfuric acid or chlorosulfonic acid in nitrobenzene at room temperature the sole product is the 4-sulfonic acid.[602] The sodium salt precipitates readily when sodium chloride is added to an aqueous solution of the acid. A different sulfonic acid results if the sulfonation is carried out at 140°.[603a] A benzyl-2-pentoxynaphthalene has also been sulfonated.[603b]

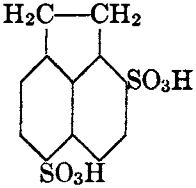
Sulfonation of Acenaphthene. The sulfonation reactions of acenaphthene are included at this point as this compound may be looked upon as being closely related to the dialkylnaphthalenes in its substitution reactions.

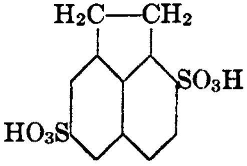
The structures of the acenaphthenesulfonic acids have been uncertain until quite recently. It has now been shown that the sulfonic acid resulting from the action of sulfuric acid at 100° which was at first[604] believed to have the sulfo group attached to a saturated carbon atom and then[605] was considered to be the 5-compound is actually[606] the 3-sulfonic acid.

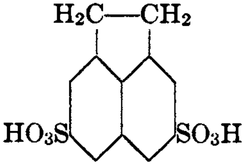


Sulfonation at 125–130° for 10 hours using one mole of chlorosulfonic acid[607] to two of acenaphthene forms the 3,3′-sulfone. Sulfonation at or near 0° in an inert solvent with chlorosulfonic acid[606b, 608] introduces the sulfo group in the 5-position. Thus acenaphthene behaves like naphthalene in that at low temperatures sulfonation occurs in the alpha position. It has been reported[605b] that four disulfonic acids are obtained from the further sulfonation of acenaphthene. These would presumably have the following structures.

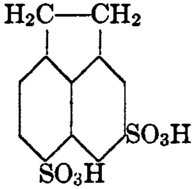








or



Whether or not it is possible to introduce two sulfo groups *peri* to each other has not been determined, although nitration does occur in this manner.[608] The results of further investigations in this series should be interesting.

SULFONATION OF THE HALO- AND NITRONAPHTHALENES

Probably the most interesting point in connection with the sulfonation of the halonaphthalenes concerns the directive influence exhibited by chlorine, bromine, and iodine in the 2-position of the naphthalene ring. The first two direct the entering sulfo group to the 6- and 8-positions while the last gives a mixture containing the 5- and 8-sulfonic acids. It was suggested by Armstrong and Wynne[609] that for all three halides the 5- and 8-compounds were formed at first, the 5- rearranging to the 6-isomer immediately where the halogen is chlorine or bromine. This occurs for the iodosulfonic acid at 150°. All three 8-sulfonic acids also rearrange to the 6-compounds under the influence of heat.

As for the other halonaphthalenes, low temperatures in all cases favor alpha substitution as for naphthalene itself. Armstrong and Wynne apparently prepared sulfonic acids and their derivatives from all the trichloronaphthalenes but for only five of these have data been recorded (see Table XVIII) in the literature.

Sulfonation of the Chloronaphthalenes. The low-temperature sulfonation of 1-chloronaphthalene with sulfuric acid[610] or chlorosulfonic acid[611] in carbon bisulfide yields chiefly the 4-sulfonic acid. Treating 1-chloronaphthalene with 100% sulfuric acid at 6° gives an 84% yield[612] of this product, a little of the chloronaphthalene remaining unchanged. As the temperature rises the yield of the 4-sulfonic acid drops rapidly;[613] at 56° it is 70%, at 78°, 57%, and at 98°, 31%. Excess chlorosulfonic acid at 30° gives a mixture of sulfonyl chlorides in which the 4-compound was identified.

There is some confusion regarding the formation of the 5-sulfonic acid. With sulfuric acid[613] as the reagent none of this compound was isolated up to 160°; at this temperature the 6- and 7-sulfonic acids[614] are produced. On the other hand earlier workers found that by the action of oleum[610b, 611b] at 160° about equal quantities of the 4- and 5-isomers resulted. The 4-compound is converted into its isomer by heating[611b] to 150°. Further sulfonation of the 4-sulfonic acid with 20% oleum at 100° gives first the 4,7-disulfonic acid[615] and then at 170° the 2,4,7-trisulfonic acid.[616] The 6-sulfonic acid may be further substituted to the 4,6-disulfonic acid[617] and the 3-sulfonic acid to the 3,5-derivative.[618] These results are summarized in Chart II.

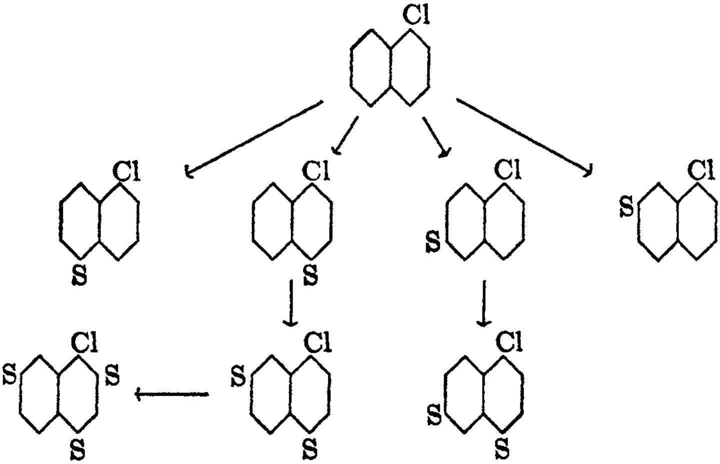


Chart II

Long heating of 2-chloronaphthalene with a mixture of sulfuric acid and oleum[619] at 130–140° yields a mixture of the 6- and 8-sulfonic acids, the latter predominating. When chlorosulfonic acid is employed[620] as the reagent in cold carbon bisulfide only 4% of the product is the 6-isomer but this is obtained in 53% yields by heating the 8-sulfonic acid to 150° for 5 hours.[620b, 621]

Excess oleum[610b] at 160–180° converts 2-chloronaphthalene into the 6,8-disulfonic acid. This is also obtained from either the 6- or 8-acid by the action of pyrosulfuric acid.[622] The 6-sulfonic acid with 20%

oleum gives as a by-product the 4,6-disulfonic acid. Sulfonation of the 7-sulfonic acid with pyrosulfuric acid[622] at 100° gives rise to the 4,7-disulfonic acid.

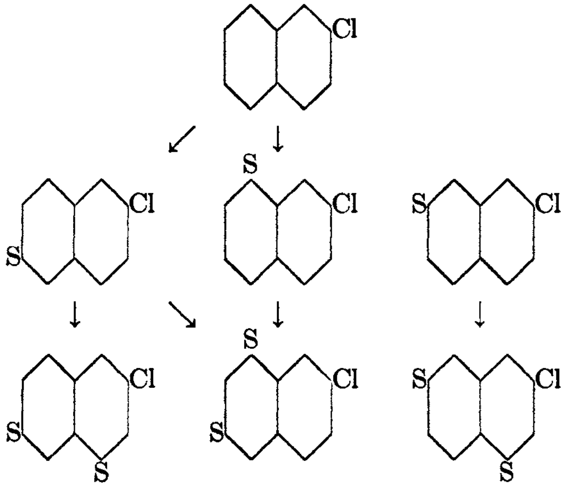


CHART III

The sulfonation reactions of the di- and trichloronaphthalenes are summarized in Table XVIII. Here as previously *A* refers to concentrated sulfuric acid, *B* to oleum, and *C* to chlorosulfonic acid. The knowledge available concerning substitution reactions in the naphthalene nucleus makes the prediction of the structure of the trichloronaphthalenesulfonic acids impossible.

Sulfonation of Bromo- and Iodonaphthalenes. Only a comparatively few derivatives of naphthalene containing bromine and iodine have been sulfonated and for most of these the structures of the resulting sulfonic acids are uncertain. However, in the case of the dibromonaphthalenes analogy with the chlorine derivatives makes the prediction of the structures fairly trustworthy. (See Table XIX, p. 281.)

It has been claimed that when 1-chloro-4-bromonaphthalene or the corresponding dichloro compound is treated with chlorosulfonic acid in carbon bisulfide[623] the chief product is the sulfone, no sulfonyl chloride and only a little sulfonic acid resulting. Since this is hardly in agreement with the work listed in Table XVIII these results seem to require further investigation.

Sulfonation of Haloacenaphthenes. Sulfonation of 5-chloroacenaphthene with 0.5 part of sulfuric acid[624] at 70° produces a sulfonic acid of unknown structure which might be expected to be the 8-compound.

The corresponding bromine derivative with chlorosulfonic acid at room temperature yields two monosulfonic acids [607,625] and with sulfuric acid at 80–90° a disulfonic acid. One of the monosulfonic acids is the 3- and the other the 8-isomer since both give the 3-sulfonic acid upon reduction.

TABLE XVIII

SULFONATION OF DI- AND TRICHLORONAPHTHALENES

Compound Sulfonated	Reagent and Reference	Reaction Data	Position of Sulfo Group
Naphthalene substituents			
1,2-Dichloro-	*C*[1,2,5]	10% sol. of $C_{10}H_6Cl_2$ in CS_2	5- and 6-
1,3-Dichloro-	*C*[1]		5- and 7-
1,4-Dichloro-	*C*[1]		6- and (?)
	A,[8] 100%	....	6- (?)
	B[3]	160°	6-
1,5-Dichloro-	*C*[1]	In CS_2	3- and (?)
	A,[8] 100%	20–25°	3-
1,6-Dichloro-	*C*[1]	In CS_2	4-
	A and *B*[4]	....	4-
1,7-Dichloro-	*C*[1,5]	In CS_2, low temperature	4-
1,8-Dichloro-	*C*[1]		4-
2,3-Dichloro-	*C*[1]		5- and 6-
2,6-Dichloro-	*C*[1]		4-
2,7-Dichloro-	*C*[1]		3- and (?)
1,2,3-Trichloro-	*B*,[1] 10%	100°	?
1,2,4-Trichloro-	*A* or *C*[1]	100°	?
1,2,7-Trichloro-	......[6]	....	?
1,2,8-Trichloro-	......[6]	....	?
1,3,6-Trichloro	......[6]	....	?
?-Tetrachloro-	*B*[7]	....	?

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[1] Armstrong and Wynne, *Chem. News*, **61**, 273 (1890).
[2] Armstrong and Wynne, *ibid.*, **60**, 58 (1889).
[3] Arnell, dissertation, Upsala, 1889.
[4] Cleve, *Ber.*, **24**, 3477 (1891).
[5] Armstrong and Wynne, *Chem. News*, **69**, 189 (1889).
[6] Armstrong and Wynne, *ibid.*, **71**, 254 (1895).
[7] Laurent, *Ann.*, **72**, 300 (1849).
[8] Badische Anilin- und Sodafabrik, German pat., 229,912, *Chem. Zentr.*, I, 358 (1911).

Sulfonation of the Nitronaphthalenes. As in the benzene series most of the sulfonic acids containing nitro groups have been prepared by nitration rather than sulfonation reactions. 1-Nitronaphthalene with sulfuric acid, oleum, or chlorosulfonic acid is converted into a mixture

TABLE XIX

Compound Sulfonated	Reagent and Reference	Reaction Data	Position of Sulfo Group
Naphthalene substituents			
1-Bromo-	B^1	....	4- and 5- (?)
	C^2	In CS_2	4- and 5- (?)
2-Bromo-	$C^{3,4}$	In CS_2	6- and 8- (?)
1,3-Dibromo-	$A,^5$ 2 parts	100°	5- and 7-
1,4-Dibromo-	$A,^{5,8,9}$ 100%	100°	6-
1,5-Dibromo	A^5	100°	7- (?)
1,6-Dibromo-	A^8	100°	4- (?)
1,7-Dibromo-	A^8	100°	4- (?)
1-Iodo-	C^6	In CS_2	4- (?)
2-Iodo-	$C^{4,7}$	In CS_2	8- and 5-
	C^4	Cold, then heat to 150°	6-

---

[1] Laurent, *Ann.*, **72**, 298 (1849); Otto and Moeries, *Ann.*, **147**, 183 (1868); Darmstaedter and Wichelhaus, *Ann.*, **152**, 303 (1869); Jolin, *Bull. soc. chim.*, [2] **28**, 516 (1877).

[2] Armstrong and Williamson, *Chem. News*, **54**, 256 (1886).

[3] Sindall, *ibid.*, **60**, 57 (1889).

[4] Armstrong and Wynne, *ibid.*, **60**, 58 (1889); **55**, 91 (1887).

[5] Armstrong and Rossiter, *ibid.*, **65**, 58 (1892).

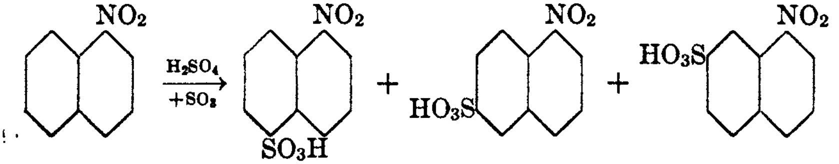
[6] Armstrong, *ibid.*, **55**, 241 (1887).

[7] Houlding, *ibid.*, **59**, 226 (1889); *Ber.*, **24R**, 705 (1891).

[8] Ephraim, *Ber.*, **51**, 668 (1918).

[9] Salkind and Belikoff, *Ber.*, **64B**, 955 (1931).

of three isomeric sulfonic acids,[626] in which the 5-compound greatly predominates.

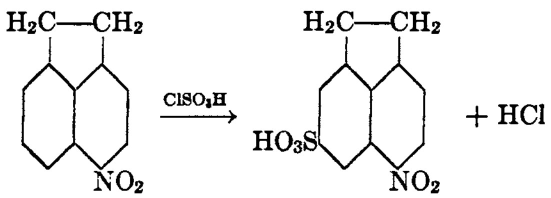


2-Nitronaphthalene with oleum[627] at a low temperature yields a mixture of the 5- and 8-sulfonic acids.

The reaction of 1,8-dinitronaphthalene with oleum[628] at 100–110° produces the 3-sulfonic acid. Under similar conditions the 1,5-dinitro compound also sulfonates in the 3-position.

When a mixture of 5- and 8-chloro-1-nitronaphthalene is treated with 100% sulfuric acid[629] at 80° for 12 hours only the 8-chloro compound reacts, sulfonation occurring *para* to the chlorine.

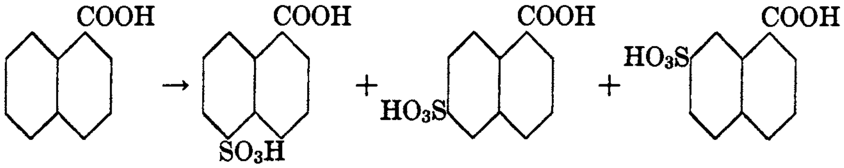
Sulfonation of 5-nitroacenaphthene with chlorosulfonic acid[630] introduces the sulfo group in the 7-position.



This gives a method of approach to the preparation of derivatives of the 4-sulfonic acid which cannot be obtained by direct sulfonation of acenaphthene.

SULFONATION OF NAPHTHALENE CARBOXYLIC ACIDS AND KETONES

Only a few compounds of the naphthoic acid type have been sulfonated. 1-Naphthoic acid reacts with oleum[631] or 98% sulfuric acid[632] at 60–70° to give a mixture of three isomeric sulfonic acids.



1-Naphthonitrile is sulfonated, probably in the 5-position, by the action of chlorosulfonic acid,[633] while with oleum[634] amide formation occurs.

2-Naphthoic acid is converted by the action of 98% sulfuric acid[635a] at 100° into a mixture of the 5-, 7-, and 8-sulfonic acids, the first predominating. At 160° the 7-isomer is formed in largest amount. None of the 6-sulfonic acid was found. The carboxyl and nitro groups thus seem to differ in directive influence considerably from the sulfo group. The sulfonation has also been effected by oleum.[631] It may be noted here that naphthalene-1-arsonic acid has been sulfonated[635b] but the structure of the resulting acid is not known.

Of the dicarboxylic acids only two have been sulfonated. 1,5-naphthalic acid with pyrosulfuric acid[636] at 190–200° is transformed into what is probably the 3-sulfonic acid. 1,8-Naphthalic anhydride with a large excess of 25% oleum[606b,637a] at 90° gives the 3-sulfonic acid. At 200–230° a disulfonic acid is obtained.

α-Naphthyl phenyl ketone sulfonates readily when treated with 95% sulfuric acid even at 20°. At 160–170° hydrolysis occurs to benzoic acid, and naphthalenedisulfonic acids result.[637b]

Sulfonation of the Naphthols and Their Derivatives

A survey of the sulfonation reactions of naphthalene compounds containing hydroxyl groups shows that practically all the attention has been centered upon 1- and 2-naphthol, undoubtedly because of the considerable value of the resulting compounds as dye intermediates. A vast amount of work remains to be done upon the sulfonation reactions of the alkyl and other simple naphthol derivatives before directive influences[554b] can be adequately discussed for this type of compound.

Sulfonation of 1-Naphthol. Sulfonation of 1-naphthol with an equal weight of sulfuric acid[638] at 60–70° produces the 2- and 4-sulfonic acids; the former was isolated in 50% yield. Using twice as much of the same reagent[638a, 639] at 50° gives rise to the 2-sulfonic acid (Schaeffer's acid) and the 2,4-disulfonic acid, the latter predominating. Weak oleum or 100% sulfuric acid[639c, 640] may also be utilized for monosulfonation if the temperature is kept low. The presence of mercuric sulfate[641] does not appreciably alter the ratio in which the 2- and 4-isomers are produced. Acetic acid is an excellent solvent for monosulfonation; sulfuric acid,[638a] 80% oleum, and chlorosulfonic acid[642] have all been used in this procedure. The presence of such a solvent prevents the monosulfonic acids from being further acted upon before the naphthol is all dissolved, which occurs when the reactants are simply mixed together. Heating sodium 1-naphthol-4-sulfonate or 2,4-disulfonate at 160–170° with naphthalene gives the naphthol-2-sulfonate.[640c] Separation of the 2- and 4-sulfonic acids is possible through the differing solubilities of their potassium salts,[638a] that of the former being the less soluble in water.

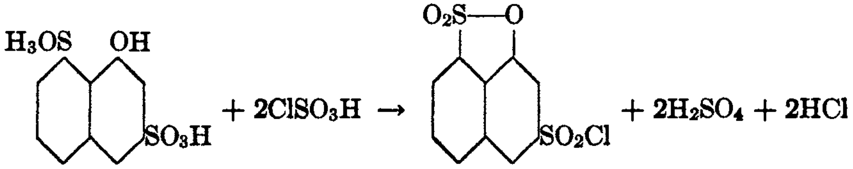
With chlorosulfonic acid[643] at ordinary temperatures 1-naphthol is converted into the 2-sulfonic acid; it is claimed[644] that at a low temperature in the presence of an inert solvent the 4-isomer results. This is also formed in the absence of a solvent[643] at 100°. With five parts of chlorosulfonic acid at room temperature for 2.5 hours the 2,4-disulfonyl chloride is produced while after several days the 2,4,7-trisulfonyl chloride is the reaction product.[645] This structure was determined by showing that the three corresponding monosulfonic acids all gave the same trisulfonyl chloride when treated with chlorosulfonic acid.

1-Naphthol with chlorosulfonic acid at 160° is converted into a resinous product from which was separated a small yield of a trichloronaphthalenesulfonyl chloride.[643]

After heating 1-naphthol with sulfuric acid at 130° the mixture contains the 2,7- and 4,7-disulfonic acids together with some 2,4,7-trisulfonic acid.[638b, 639c, d, 646] This trisulfonic acid gives a characteristic insoluble barium salt which makes its determination a simple matter. When 2.5 parts of sulfuric acid is heated with the 1-naphthol for 4 hours at 125° approximately one-seventh of the naphthol is transformed into the trisulfonation product.[638b]

By dissolving 1-naphthol in oleum below 100° the 2,4-disulfonic acid is obtained as the chief product.[639c, 646, 647] If after dissolving in 25% oleum at 50°, 70% oleum [648] is added at room temperature the 2,4,7-trisulfonic acid again becomes the reaction product.

A number of naphtholsulfonic acids not necessarily obtained by direct sulfonation have been converted into di and trisulfonic acids. 1-Naphthol-5-sulfonic acid with sulfuric acid [649a] below 100° is sulfonated in the 2-position. The 8-sulfonic acid or its sultone by treatment with sulfuric acid at 100° or with cold oleum is converted into 1,8-naphthosultone-4-sulfonic acid.[649b] Chlorosulfonic acid yields sulfonyl chlorides with this and with other naphthosultone sulfonic acids.[649c] The action of chlorosulfonic acid [650] upon the 3-, 5-, 6-, and 8-sulfonic acids yields trisulfonyl chlorides. Since 1-naphthol-4,6- and 6,8-disulfonic acids give the same trisulfonyl chloride this compound is established as the 4,6,8-compound. This trisulfonyl chloride also results from the 8-sulfonic acid. The trisulfonyl chloride from 1-naphthol-6-sulfonic acid is probably the 2,6,8-compound while the one from the 5-sulfonic acid is either the 2,5,7- or 3,5,7-trisulfonyl chloride, more probably the former. 1-Naphthol-3,8- and 4,8-disulfonic acids are converted into naphthosultone-3- and 4-sulfonyl chlorides respectively by treatment with chlorosulfonic acid at room temperature.



With oleum the corresponding sultone-sulfonic acid results.[650b] At 150° the 4,8-compound is transformed by chlorosulfonic acid into the 4,6,8-trisulfonyl chloride. These results are summarized in Chart IV.

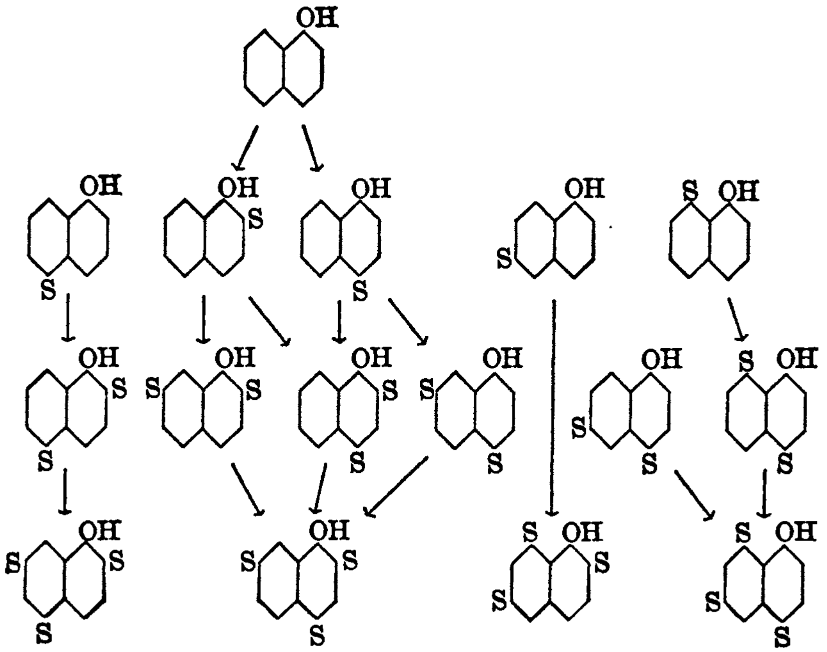


CHART IV

Sulfonation of 2-Naphthol. The sulfonic acids derived from 2-naphthol have been investigated even more fully than those of the 1-isomer. Perhaps the most interesting of these is the 1-sulfonic acid which is characterized by the ease with which the sulfo group is removed or rearranged to other positions of the naphthol nucleus.

With 2–2.5 parts of sulfuric acid at 40° for 10 minutes [651] or at 10° for an hour [651d] 2-naphthol is converted into the 1-sulfonic acid as the major product while for longer reaction times a mixture containing the 6-, 7-, and 8-sulfonic acids, together with the 6,8-disulfonic acid results.[651a,c,e,652] Keeping the temperature at 20° or below has been reported to favor the 8-sulfonic acid contradicting the observation noted above, while at 100° the 6-isomer is the major product.[639a,651a] It is reported that by heating 2-naphthol with 0.7 part of sulfuric acid [655] at 100–105° the 6- and 7-sulfonic acids result, but no other mention of the formation of the 7-sulfonic acid is found in the literature until recently.[651e]

By the addition of a small amount of boric acid [654] to 2-naphthol it has been reported that the 1-sulfonic acid may be made to persist in the sulfonation mixture for some time rather than being a transitory product but this claim has been denied.[651d] A comparison of the results of Table XX with those of Table XXI, however, upholds this suggestion. In Table XX are given the yields of the various sulfonic acids obtained for a number of reaction conditions. With the exception of the first experiment the reagent was 94.2% sulfuric acid and the reaction time 24 hours. In the first experiment 100% sulfuric acid was used with a reaction time of 4 minutes.

TABLE XX

SULFONATION OF 2-NAPHTHOL

Wt. of Acid / Wt. of Naphthol	t, °C.	Product Yields, Percentage of Sulfonated Naphthol			
		1-	6-	8-	1,6-di-
2	20–30	62	12	17	9
10	2	..	3	23	74
5	18	..	11	38	51
2	25	..	23	54	23
2	32	..	33	54	12
1.5	56	..	47	46	7
1.3	75	..	60	28	1
1.1	85	..	74	11	..

TABLE XXI

SULFONATION IN PRESENCE OF BORIC ACID

Wt. of Sulfuric Acid / Wt. of Naphthol	t, °C.	Time	Product Yields, Percentage of Sulfonated Naphthol			
			1-	6-	8-	1,6-di-
2	20–28	4 min.	90	9	Trace	..
2	30	24 hrs.	74	3	10	13
10	0	30 hrs.	Trace	2	17	81
5	25	30 hrs.	Trace	3	21	76
2	85	1 hr.	.....	20	27	53

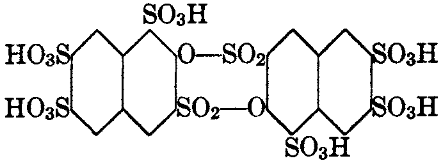
It is remarkable that the disulfonation decreases with rise in temperature even when the amount of sulfonating agent remains constant.

The influence of boric acid upon the sulfonation is shown in Table XXI. Here 1.5 g. of metaboric acid was added per 0.1 mole of the naphthol. Here also 100% sulfuric acid was employed in the first experiment. In the others the concentration was 94.2%.

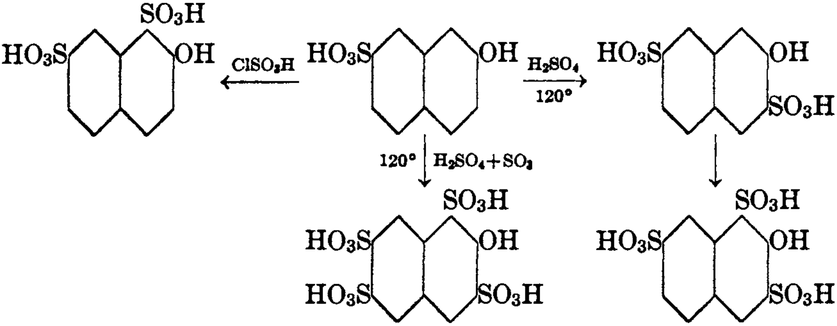
Chlorosulfonic acid reacts similarly to sulfuric acid as a monosulfonating agent since at ordinary temperatures[651a,655] the 1-sulfonic acid results while at 130° in acetylene tetrachloride[655a] the 6-isomer is produced. With sulfur trioxide,[656] in the same solvent in the presence of boric acid the 1-sulfonic acid is the reaction product. The use of nitrobenzene as the solvent and a temperature below 16° has also been patented.[657] In a comparison[658] of several commercial methods for preparing the 1-sulfonic acid, the procedure utilizing sulfuric acid as the reagent and calling for a removal of the product from the reaction zone by crystallization[659] was found to be the most satisfactory, an 80% yield of the acid being obtained.

In addition to the 1,6-disulfonic acid obtained in the sulfonations already described, two other disulfonation products have been isolated. By heating 2-naphthol with oleum[660] at 100–110° for 12 hours a mixture of the 3,6- and 6,8-disulfonic acids (R and G acids respectively) is obtained. This result has also been attained by the action of four parts of sulfuric acid[661] at 125–150° for 5 or 6 hours. With three parts of sulfuric acid at 135° for 24 hours 33% of the 6,8- and 43% of the 3,6-isomers result, while in the presence of boric acid[654] 28% of the 1,6-, 31% of the 6,8-, and 39% of the 3,6-isomers are formed. A lower temperature and longer reaction time[662] favor formation of the 6,8-compound. Thus with five parts of 20% oleum at 20–25° for 8 hours[663] 50 g. of the barium 6-sulfonate, 61 g. of the sodium 6,8-disulfonate, and 22 g. of the sodium 3,6-disulfonate are produced. Somewhat better yields of G acid are obtained by separating it as the potassium salt and the R acid as the sodium salt. Separation of the 3,6-disulfonic acid from the 6-sulfonic acid may be accomplished by precipitating the former as its sodium salt in the presence of sodium chloride.[664] An 84–85% yield of the 3,6-compound contaminated with only about 9% of the 6-sulfonic acid results from the action of 10% oleum[665] at 120–125° for 18 hours or at 130–135° for 12 hours. Higher temperatures lead to excessive amounts of trisulfonation. A smaller percentage of sulfur trioxide increases the yield of the 6-sulfonic acid.

Sulfonation of 2-naphthol-6-sulfonic acid with potassium pyrosulfate and sulfuric acid[666] gives the 3,6-disulfonic acid while further sulfonation of the 8-sulfonic acid produces the 6,8-isomer.[667] 2-Naphthol-3,6,8-trisulfonic acid results from the action of 20% oleum[668] at 140–160°. With 40% oleum[669] at 120–130° for 8 hours, sodium 2-naphthol-1-sulfonate yields the 1,3,6,7-tetrasulfonic acid. This is one of the rare instances of two sulfo groups entering an aromatic ring *ortho* to each other. If the sulfonation is allowed to proceed for two days the corresponding sulfonylide is formed. The indicated structure is the most probable one.



The further sulfonation of 2-naphthol-7-sulfonic acid has been investigated.[670] The equations indicate the products obtained under various reaction conditions.



With excess chlorosulfonic acid at ordinary temperatures 2-naphthol gives rise to a mixture of two disulfonyl chlorides[656a] one of which is the 1,6-[671] and the other the 1,5-isomer.[672] The structure of the former is evident from its production from both the 1- and 6-sulfonic acids when these are treated with chlorosulfonic acid, while the 1,5-compound results from the 2-naphthol-5-sulfonic acid. 2-Naphthol-8-sulfonic acid is further sulfonated to the 6,8-disulfonyl chloride. The 3,6-disulfonyl chloride of carbethoxy-2-naphthol was prepared from the corresponding disulfonic acid through the action of chlorosulfonic acid. 2-Naphthol-7-sulfonic acid is converted to the 1,7-disulfonyl chloride through this reagent.

The 1,6- and 1,5-disulfonyl chlorides upon further treatment with chlorosulfonic acid[671] yield the 3,6,8-trisulfonyl chloride, rearrangement occurring. This trisulfonyl chloride also results from the action of excess chlorosulfonic acid upon 2-naphthol at 130–140°. By heating at 150–160° for 80 hours two unidentified compounds were formed. Chart V summarizes the 2-naphthol reactions.

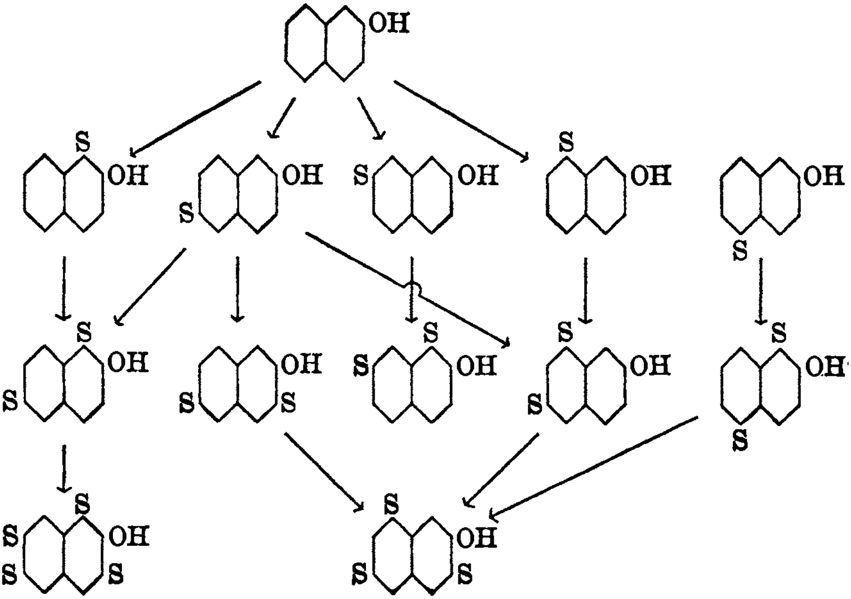


CHART V

Sulfonation of Naphthyl Ethers and Esters. At room temperature[673] or at 100° sulfuric acid converts 1-naphthyl ethyl ether[674] into the 4-sulfonic acid. Care is necessary in crystallizing this compound from water as at 75° it hydrolyzes considerably. 2-Naphthyl methyl ether with chlorosulfonic acid[675] in carbon bisulfide yields a mixture of the 6- and 8-sulfonic acids whereas the corresponding ethyl ether and this reagent in cold chloroform[676] give first the 1-sulfonic acid which upon standing undergoes rearrangement to a mixture of the 6- and 8-sulfonic acids. Sulfonation at room temperature with chlorosulfonic acid in carbon bisulfide[677] or with sulfuric acid[674] forms the 6- and 8-sulfonic acids directly. Disulfonation in chloroform with chlorosulfonic acid[676] gives rise to the 1,6-disulfonic acid.

Sulfonation of 1-naphthyl carbonate with four parts of sulfuric acid[678] at 20° for 18 hours produces the 4,4′-disulfonic acid which is readily hydrolyzed to the 1-naphthol-4-sulfonic acid. None of the 2-isomer was found. Further sulfonation occurs in the 6,6′-positions.[679] 1-Acetoxynaphthalene-5-sulfonyl chloride with 4% oleum[580b] probably gives the 4-sulfonic acid.

2-Naphthyl acetate sulfonates in the 1-position with chlorosulfonic acid.[655b]

Sulfonation of Substituted Naphthols. Aside from the amino derivatives of the naphthols which are considered later, information concerning sulfonation reactions of substituted naphthols is limited to a few miscellaneous compounds.

1-Bromo-2-naphthol reacts with chlorosulfonic acid [680] to give the 6-sulfonic acid. This is also obtained from bromination of the 6-sulfonic acid which establishes its structure. 1-Chloro-2-naphthol behaves similarly. Sulfonation of 1,3-dichloro-, 1,4-dichloro-, 1,3,5-trichloro-, and 1,4,5-trichloro-2-naphthol yields a 6-sulfonic acid in each instance. This makes clear the difficulty encountered in the sulfonation of 1,6-dibromo-2-naphthol and the 1-chloro-6-bromo compounds in which the 6-position is already occupied.[680d] If the 1-position is unoccupied as in 6-bromo-2-naphthol the sulfo group enters there.[681]

2-Nitro-1-naphthyl ethyl ether is converted by sulfuric acid [674b] to the 6-sulfonic acid. 1-Hydroxy-2-naphthyl methyl ketone with the same reagent at 100° sulfonates in the 4-position.[682a] 1-(2-*p*-Toluenesulfonamidobenzoyl)-2-methoxynaphthalene reacts with sulfuric acid [682b] with loss of the toluenesulfonyl group and introduction of a sulfo group.

The hydroxynaphthoic acids have been investigated somewhat more fully than the foregoing compounds. 1-Hydroxy-2-naphthoic acid reacts with oleum to give first [683] the 4-sulfonic acid and then [684] the 4,7-disulfo compound. With cold chlorosulfonic acid [331] the 4-sulfonyl chloride is the reaction product. 2-Hydroxy-1-naphthoic acid with oleum [685] at 20° sulfonates in the 6-position and with chlorosulfonic acid in the cold [331] the corresponding sulfonyl chloride results.

At a low temperature both 2-hydroxy-3-naphthoic acid and its anilide react with chlorosulfonic acid [655b] to produce the 1-sulfonic acid. This shows considerably greater stability than the corresponding 2-naphthol derivative; for example, further sulfonation in the 6-position may be effected without migration of the 1-sulfo group. With excess cold chlorosulfonic acid [681] the 1-sulfonyl chloride is the reaction product.

By sulfonation of 2-hydroxy-3-naphthoic acid with 3.4 parts of sulfuric acid or weak oleum [686] at 60° for 12 hours a mixture of the 6- and 8-sulfonic acids results. Further sulfonation with oleum at 120° gives the 6,8-disulfonic acid.

1-Hydroxy-4-naphthoic acid has been found to sulfonate in the 2-position when treated with sulfuric acid.[687a] 2-Hydroxy-6-naphthoic acid with sulfuric acid yields a mixture of the 3- and 8-sulfonic acids.[687c]

The action of oleum upon 3-hydroxy-1,8-naphthalic acid at 115–120° produces a monosulfonic acid.[687b]

Sulfonation of Dihydroxynaphthalenes. Only a few of the dihydroxynaphthalenesulfonic acids have been prepared by sulfonation reactions. Of these the 2,7-dihydroxy compound is of considerable interest as the disulfonic acid obtained by the action of sulfuric acid at 100° probably has the 3,6-structure,[688] positions which would not be expected to substitute upon the basis of a fixed [689] structure of the naphthalene nucleus.

2,6-Dihydroxynaphthalene with 100% sulfuric acid [690] yields the 4-mono and a disulfonic acid while the 1,8-compound gives two disulfonic acids.[691] None of these three acids is of known structure. 1,5-Dihydroxynaphthalene when treated with sulfuric acid at 50–60° is sulfonated in the 2-position.[692] Sulfonation of 1,2-naphthoquinone [693] gives rise to 1,2-dihydroxynaphthalene-4-sulfonic acid. On the other hand 2-hydroxy-1,4-naphthoquinone is converted into the 3-sulfonic acid without reduction occurring.[694]

The 3,5- and 3,7-dihydroxy-2-naphthoic acids have been converted into monosulfonic acids.[695]

Sulfonation of the Naphthylamines and Their Derivatives

In the sulfonation of the naphthylamines, as for other naphthalene derivatives, the reaction temperature has a marked influence upon the position taken by the sulfo group. At 100° or below substitution occurs primarily in an alpha position while above 160° the beta sulfonic acids predominate. Compared with the exhaustive study which has been made of the sulfonation reactions of the 1- and 2-naphthylamines, derivatives of these have received little attention. Most of the technically important aminonaphtholsulfonic acids have been made by reactions other than direct sulfonation.

Sulfonation of 1-Naphthylamine. Four of the seven possible 1-naphthylaminesulfonic acids, all of which are known, are obtainable by the direct sulfonation of the amine.[554b] All seven monosulfonic acids have been converted into di or trisulfonic acids by sulfonation reactions. These results are summarized in Chart VI.

1-Naphthylamine-2-sulfonic acid is obtained as the ammonium salt by heating the amine with sulfamic acid [696] at 180–185°. The sodium salt of 1-naphthylaminosulfonic acid ($C_{10}H_7NHSO_3H$) rearranges [697]

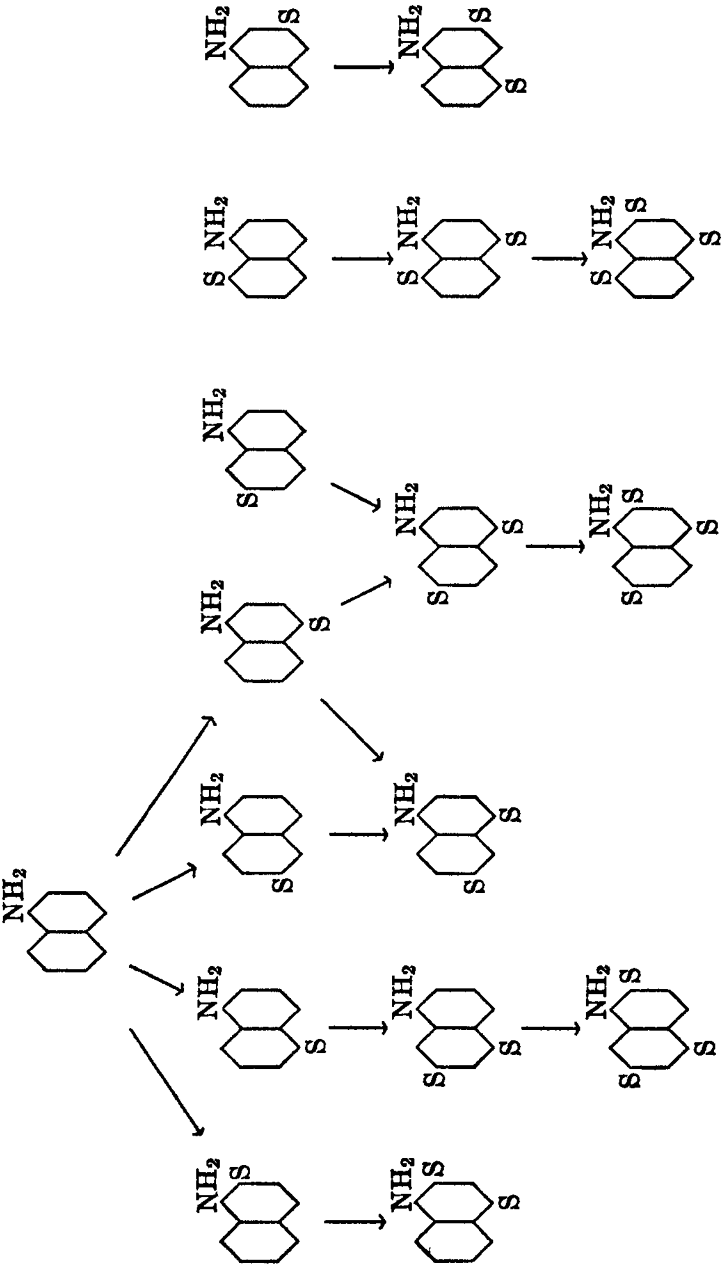


CHART VI

when heated in a stream of carbon dioxide at 185–190° to the 2-acid. Sodium naphthionate likewise rearranges in carbon dioxide[698] at 200–250° or better in boiling naphthalene[699] to give an 80% yield of the 2-isomer. Heating 1-naphthylamine with various aromatic aminosulfonic acids[700] such as sulfanilic acid also gives the 2-sulfonic acid. Since all these methods of preparation involve high temperatures the report that the 2-sulfonic acid results from the action of chlorosulfonic acid upon the amine in a solvent at a low temperature[888] may be regarded with some skepticism, particularly since the claim in the patent was found to be erroneous in the case of aniline.[889]

When 1-naphthylamine is treated with one molecular equivalent of sulfuric acid[701] at 180–200° under the conditions of the baking process (see p. 245) the 4-sulfonic acid is the sole product. This is also obtained at 200° when potassium trihydrogen disulfate[702] is the reagent. An 80% yield of the crude naphthionic acid results from heating 200 g. of the amine with 157 g. of 96% sulfuric acid and 600 g. of sodium sulfate under carefully controlled conditions,[703a] strong agitation being desirable and the temperature not going above 210°. Removal of unchanged amine from the reaction product was effected by the use of diazotized benzidine. The effect on the reaction rate and the products of adding ferrous, cupric, aluminum, nickel, silver, and mercuric sulfates and vanadium pentoxide has been reported in detail.[703b] In general, the effects were slight and apparently without advantage. The highest yield of 2-sulfonic acid observed was 3.3%.

When 1-naphthylamine is warmed with oleum it is changed into a mixture of the 4- and 5-sulfonic acids.[704] The 5-isomer is the chief product when 1-naphthylamine hydrochloride is dissolved in 20–25% oleum[704d, 705] at 0°. Separation of the 4- and 5-isomers may be accomplished through the differing solubilities of their sodium salts.[704e]

When 1-naphthylamine is heated to 125–130° with three to five parts of sulfuric acid[698b, 704d, e, 706] there results a mixture containing the 5- and 6-sulfonic acids together with the 4,7-disulfonic acid. These may be separated by conversion into the calcium salts, treating with hot absolute alcohol to dissolve the 5-compound and cold methanol to remove the 4,7-disulfonate. The 6-sulfonate remains undissolved.[698b]

The products obtained from 1-naphthylamine and chlorosulfonic acid[707] are similar to those from oleum, the 4- and 5-sulfonic acids predominating.

The 1-naphthylaminedi- and trisulfonic acids have frequently been prepared from partially sulfonated compounds rather than from the amine itself. This is partly because of the difficulty encountered in

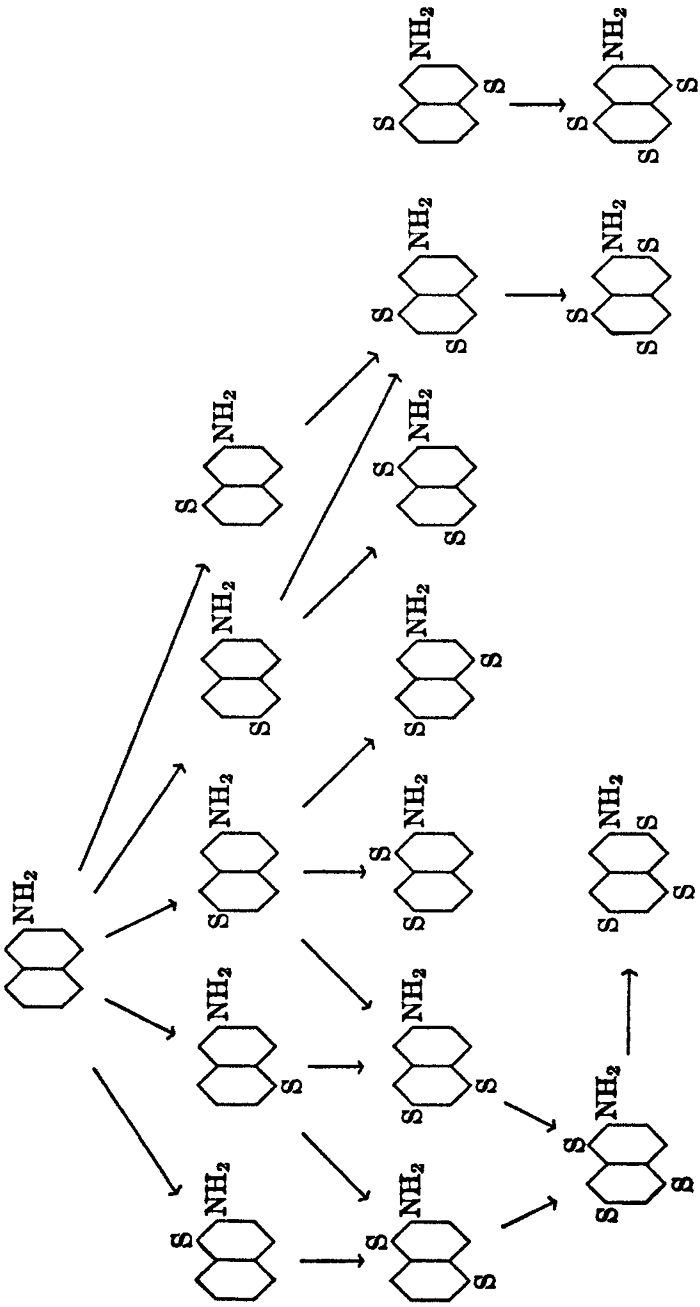
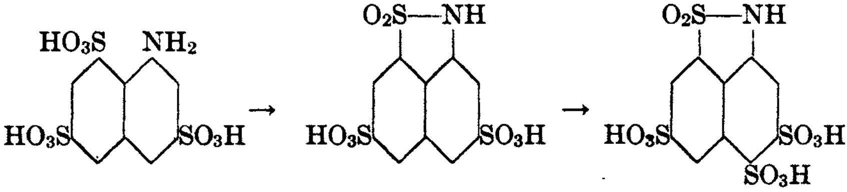


CHART VII

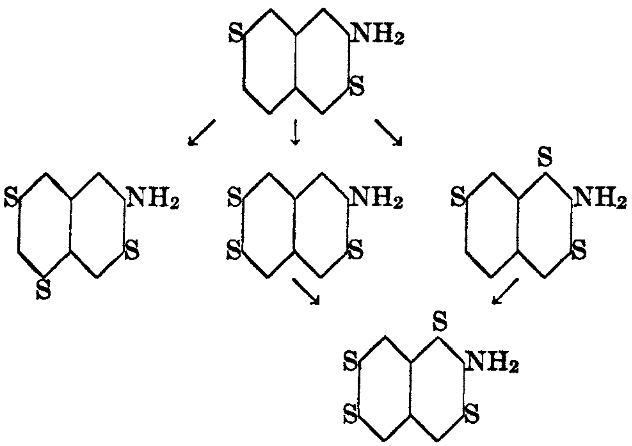
separating the components of the mixture obtained from the amine. 1-Naphthylamine with oleum[698b,708] at 120° yields a mixture of the 4,6- and 4,7-disulfonic acids together with an unidentified compound. These two disulfonic acids and the 2,4,7-trisulfonic acid result from the action of oleum[698,708,709] at 30° upon naphthionic acid. At 120° the trisulfonic acid becomes the chief product.[710] The 2-sulfonic acid reacts with oleum or chlorosulfonic acid[698,711] to form the 2,5-disulfonic acid. The 3-sulfonic acid with 20% oleum below 20° also[712] sulfonates in the 5-position. Further sulfonation of the N-acetyl-5-sulfonic acid[713] with sulfuric acid produces the 5,7-disulfo compound while with oleum the corresponding unacetylated derivative gives rise to the 2,5,7-trisulfonic acid.[714] The action of oleum[715] at 100–150° upon the 1-naphthylamine-6-sulfonic acid converts it into the 4,6-disulfonated compound, further sulfonation with oleum or chlorosulfonic acid giving the 2,4,6-trisulfonic acid.[716] The 7-sulfonic acid[717] yields the 4,7-disulfonic acid.

1-Naphthylamine-8-sulfonic acid when treated with oleum[709,718] at 100° sulfonates in the 4-position while with sulfuric acid at 75–80° it rearranges to naphthionic acid.[719] The N-acetyl derivative is claimed[720] to sulfonate in the 6-position. The 4,8-compound may be sulfonated further[721] to the 2,4,8-trisulfonic acid.

The action of 25% oleum[722] upon the 3,6,8-trisulfonic acid converts it into the sultam and then into the sultam of a tetrasulfonic acid.



Sulfonation of 2-Naphthylamine. Five of the six known monosulfonic acids of 2-naphthylamine may be prepared by direct sulfonation. These may be arranged in a series of increasing stability toward heat; the least stable 1-sulfonic acid has been prepared by a sulfonation reaction only recently while the most stable 6-sulfonic acid is practically the sole product at sulfonation temperatures of 200° or above. The stability series may be written: $1 < 8 < 5 < 7 < 6$. Of these relationships only the conversion of the 1- to the 8-isomer has not been effected in good yield. All sulfonation reactions of 2-naphthylamine are summarized in Chart VII. In addition there is the series of products obtained from the 3,7-disulfonic acid through sulfonation to the tri- and tetrasulfonic acids.



Despite the thoroughness with which the sulfonation reactions of 2-naphthylamine have been investigated, contributions to our knowledge of these reactions are still appearing in the literature.

Through the action of sulfur trioxide upon a solution of the amine in an inert solvent[723] at not over 90° the 1-sulfonic acid is obtained. This with 96% sulfuric acid at 80° rearranges into a mixture[724] of 5- and 8-isomers. When 2-naphthylamine stands with sulfuric acid for many days[698, 725] the 5- and 8-sulfonic acids predominate in the reaction mixture, the former being present in 55% yield. At 100–105° with 3–3.5 parts of this reagent[726] there are formed 40% of the 5-, 50% of the 8-, and 5% each of the 6- and 7-sulfonic acid. Analysis of this mixture is possible because of the insolubility of the sodium 8-sulfonate in 90% alcohol and the differing solubilities in water of the barium salts of the other three acids. The sodium salts of the 5- and 8-sulfonic acids also differ considerably in their solubilities in water.[727] Separation of the 8-sulfonic acid from the others may also be effected by fractional precipitation by the addition of sulfuric acid to a solution of the mixed sodium salts.[728] As the temperature of sulfonation is raised the 6- and 7-sulfonic acids become predominant; about equal amounts are formed with 3–3.5 parts of sulfuric acid[704c, 726, 729] at 160–170°. If the temperature is raised to 200–210° one molecular equivalent of sulfuric acid yields only the 6-sulfonic acid.[730] Potassium trihydrogen sulfate[702] at 230° also gives almost entirely the 6-sulfonic acid.

By warming the amine with 20% oleum[731] at 70–80° a mixture is produced which contains 68–70% of the 5-, 30% of the 8-, and a trace of the 6-sulfonic acid. This reaction has more recently been investigated in detail.[732] Chlorosulfonic acid gives similar results.[707] If the 8-sulfonic acid is heated to 80–120° with 10–96% sulfuric acid [724] it is transformed into the 5-isomer mixed with a little of the 6- and 7-compounds. When cither the 5- or 8-sulfonic acid is heated at 160° with sulfuric acid [733] it rearranges into a mixture of the 6- and 7-isomers.

The di and trisulfonation products of 2-naphthylamine have received considerable attention even in more recent years although the general outline of the results was well established some forty to fifty years ago. Addition of 2-naphthylamine sulfate to 20–30% oleum [734] and heating to 110–140° produces the 6,8-disulfonic acid (amino G acid). The simultaneous preparation of this compound and the 5,7-isomer (amino I acid) has been exhaustively investigated. The preparation of the latter compound involves the trisulfonation of the amine to the 1,5,7-trisulfonic acid followed by removal of the 1-sulfo group by hydrolysis. This trisulfonation is desirable since the 1,5-disulfonic acid is converted into the 1,5,7-compound and there are only two products to separate from the sulfonation mixture. Typical directions for the sulfonation are those of Fierz-David and Braunschweig [735] who dissolve 192 g. of 2-naphthylamine in 750 g. of 100% sulfuric acid, keep at 40° for 1 hour, add 700 g. of 62% oleum, and heat at 85–90° for 11 hours. After pouring the mixture into 2600 g. of ice and water and standing for 4 hours the 6,8-disulfonic acid separates quantitatively; the yield after recrystallization from hydrochloric acid is 41%. The filtrate containing the 1,5,7-trisulfonic acid is boiled and cooled to give the 5,7-disulfonic acid. Formation of the 1,5,7-trisulfonic acid also occurs when the 5-sulfonic acid or the 1,5- and 5,7-disulfonic acids are treated with 40% oleum [709,736] at 100°. The 1,5-compound is not affected by 85% sulfuric acid at room temperature [737] but at 100° hydrolysis to the 5-sulfonic acid occurs and at higher temperatures a mixture of the 6- and 7-compounds is formed. By the action of oleum upon the 6-sulfonic acid below 20° further sulfonation occurs, chiefly in the 1-position,[738] while the 8-sulfonic acid sulfonates, after long standing, in the 6-position.[709] The 5-sulfonic acid under these conditions yields mainly the 5,7-compound with a little of the 1,5-isomer while the 1-sulfonic acid gives entirely the 1,5-disulfo compound.[712,737] The 7-sulfonic acid with four parts of cold 25% oleum gives rise to a mixture of three compounds,[739] the 5,7-, 1,7-, and 4,7-disulfonic acids.

By the action of 40% oleum at 80–90° the 6,8-disulfonic acid [722b] sulfonates in the amino group but at 120–130° the 3,6,8-trisulfonic acid results. When the 3,7-disulfonic acid is heated with 40% oleum at 130° there results a mixture [740] containing the 3,6,7-, 3,5,7-tri-, and

1,3,6,7-tetrasulfonic acids. The 1,3,7-trisulfonic acid with 10–20% oleum yields a mixture of this tetrasulfonic acid and the 3,5,7-trisulfonated compound, the latter through rearrangement. The 3,5,7- and 3,6,7-trisulfonic acids are readily separable as their sodium salts. The 3,6,7-trisulfonic acid by treatment with oleum is converted into the 1,3,6,7-tetrasulfonic acid, and this may be readily hydrolyzed back to the 3,6,7-compound. The 1,5,7-trisulfonic acid when heated with oleum [741] at 140–160° rearranges to the 3,5,7-compound. By heating the 4,8-disulfonic acid with 60% oleum [742] at 100° for 10 hours, then at 120° for 2 hours a good yield of the 4,6,8-trisulfonic acid was obtained.

The sulfonation of 4-methyl-1-naphthylamine [743a] gives a mixture of the 3- and 6-sulfonic acids. The alkali salts of the 6-compound are less soluble in water than those of the 3-isomer.

Apparently no other amino derivative of an alkylnaphthalene in which the amino group is attached to the nucleus has been sulfonated. 5-Aminoacenaphthene reacts with sulfuric acid in the 3-position.[743b]

Sulfonation of N-Substituted Naphthylamines. 1-Naphthylmethylamine [744] is converted by sulfuric acid into a mixture of the 2- and 4-sulfonic acids which further react to give the 2,4-disulfo compound. These reactions are more analogous to those of methylnaphthalene than to the ring-substituted amines. Sulfonation of N,N-dimethyl-1-naphthylamine with sulfuric acid [745] at 130° gives the 5-sulfonic acid and an isomer. At 120–130° with oleum [745b] a disulfonic acid results which, however, was not described. N,N-Diethyl-1-naphthylamine has been converted into a sulfonic acid by the action of sulfuric acid [746a] at 190–210°. It seems probable that this is the 6-isomer.

N-Ethyl-2-naphthylamine hydrochloride with "weak" oleum [746b] at ordinary temperature gives the 5-sulfonic acid while with 100% sulfuric acid at 140° the 7-isomer is the principal product. Both of these undergo further sulfonation with oleum to the 5,7-disulfo compound. N,N-Dimethyl-2-naphthylamine-5-sulfonic acid reacts with chlorosulfonic acid [747] to yield a mixture of two monosulfonyl chlorides of undetermined structure.

N-Phenyl- and N-*o*-tolyl-2-naphthylamine sulfonate in the 5- or 8-position when allowed to stand with four parts of 100% sulfuric acid.[748]

Sulfonation of N-acetyl-1-naphthylamine with oleum [749a] gives rise to a mixture of the 4- and 5-sulfonic acids. With chlorosulfonic acid [747] the 4-sulfonyl chloride is obtained. As already noted (see p. 295) N-acetyl-1-naphthylamine-8-sulfonic acid sulfonates in the

6-position.[720] Amides derived from higher-molecular-weight fatty acids and N-ethylnaphthylamine upon sulfonation yield wetting agents.[749b]

N-Acetyl-2-naphthylamine with sulfuric acid[750] substitutes chiefly in the 8-position whereas with chlorosulfonic acid a sulfonyl chloride[751] of unknown structure results.

Sulfonation of Chloroaminonaphthalenes. Only a few of the halogenated aminonaphthalenes have been sulfonated. 8-Chloro-1-naphthylamine with oleum[752] at a low temperature yields the 5-sulfonic acid. The sulfonic acid from the 2,4-dichloro-N-acetyl compound is of unknown constitution.[753] 1-Chloro-2-naphthylamine hydrochloride with 2% oleum at 70° for 6 hours[754] is converted chiefly into the 5-sulfonic acid; at 100° the 6- and at 160° the 7-isomer predominates. The N-acetyl derivative also sulfonates in the 5-position at a low temperature.[755]

Sulfonation of Aminonaphthols. Although the hydroxyaminonaphthalenesulfonic acids are of importance in the preparation of certain dyes only a few compounds of this category have been obtained by sulfonation reactions. Of these the most studied are those derived from 8-amino-1-naphthol. This compound with sulfuric acid[756] at 15–20° gives a mixture of the 2- and 4-sulfonic acids, separable through the difference in solubilities of their calcium salts. With 75% sulfuric acid at 130–160° the 2-isomer is the sole product.[757] Further sulfonation at 100° with sulfuric acid yields the 2,4-disulfonated compound.[758] The 5-sulfonic acid is converted into the 2,5-disulfonic acid when treated with 100% sulfuric acid or 23% oleum[759] while the 6-isomer yields the 4,6-disulfonic acid.[760] The results obtained with other aminonaphthols are shown in Table XXII. Under the "reagent" column, *A* refers to sulfuric acid and *B* to oleum.

Sulfonation of Diaminonaphthalenes. The investigations of the sulfonation reactions of these compounds are with one exception reported only in the patent literature. 1,8-Diaminonaphthalene sulfate when heated at 100° or above[761] yields the 4-sulfonic aid. This when treated with 60% oleum[762] at 70–80° gives a disulfonic acid of unknown structure. If the sulfo groups occupy the *peri* position it seems to be one of the rare instances where such a sulfonation occurs. 1,5-Diaminonaphthalene sulfate when dissolved in 5% oleum and the solution treated with 25% oleum[763] followed by heating at 100–110° sulfonates in the 2-position.

N-Acetyl-1,4-diaminonaphthalene reacts in the 7-position when treated with 20% oleum[764] at not over 25–30°. Low-temperature re-

TABLE XXII

SULFONATION OF AMINONAPHTHOLS

Naphthalene Derivative	Reagent and Reference	Reaction Data	Position of Sulfo Group
2-Amino-1-hydroxy-	*A*[10]	20–30°	4- (?)
4-Amino-1-hydroxy-	*B*,[1] 10%	....	2-
5-Amino-1-hydroxy	*A*[2]	....	2- (?)
6-Amino-1-hydroxy-	*A*[8]	....	2- and 4-
7-Amino-1-hydroxy-	*A*[9]	20–30°	2- and 4-
4-Amino-2-hydroxy-	*A*,[3] 4 parts	....	1-
7-Amino-2-hydroxy-	*A*[11]	....	1,?-di-
8-Amino-2-hydroxy-	*A*[4]	20–30°	5-
6-Amino-1-hydroxy-5-sulfo-	*A*[7]	Cold	2-
		Warm	2,4- (rearranges)
3-Amino-2-hydroxy-7-sulfo-	*A*[6]	....	5-
5-Amino-2-hydroxy-7-sulfo-	*A*[5]	140–150°	3-
1-Phenylamino-2-hydroxy-	*A*,[12] 100%	45–50°	Not 4-

[1] Seidel, *Ber.*, **25**, 424 (1892).

[2] A.-G. für Anilinfabrik, German pat., 68,564, *Frdl.*, **3**, 486.

[3] Friedländer and Rüdt, *Ber.* **29**, 1609 (1896).

[4] Cassella and Co., German pat., 69,485, *Moniteur scientifique du Dr. Quesneville, Paris*, **38**, 319 (1892); 75,066, *Frdl.*, **3**, 476.

[5] Cassella and Co., German pat., 84,952, *Frdl.*, **4**, 576.

[6] A.-G. für Anilinfabrik, German pat., 86,448, *Frdl.*, **4**, 606; Cassella and Co., German pat., 116,768, *Chem. Zentr.*, I, 153 (1901).

[7] Bucherer and Wahl, *J. prakt. Chem.*, [2] **103**, 129 (1921).

[8] Bayer and Co., German pat. appl., 7,372, *Frdl.*, **4**, 577.

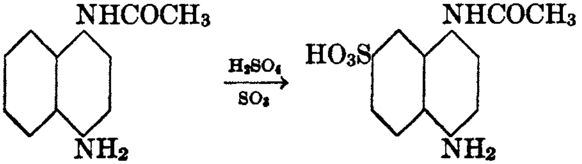
[9] Bayer and Co., German pat. appl., 7,335, *Frdl.*, **4**, 640.

[10] Kern and Sandoz, German pat., 69,228, *Moniteur scientifique du Dr. Quesneville, Paris*, 171 (1893).

[11] Cassella and Co., German pat., 131,526, *Chem. Zentr.*, I, 1382 (1902).

[12] Lautz and Wall, *Compt. rend.*, **180**, 1668 (1925).

actions usually give alpha sulfonic acids but here the groups in the *peri* position apparently prevent this.



SULFONATION OF ANTHRACENE AND RELATED COMPOUNDS

In comparison with naphthalene the sulfonation reactions of anthracene have been little investigated. The sulfonation of anthraquinone on the other hand has been studied thoroughly. Of the various anthraquinone derivatives the hydroxy compounds have received the most attention, but the information concerning these compounds comes almost entirely from the older patent literature and is restricted to their preparation and technical usefulness. Very noticeable is the lack of information concerning the action of chlorosulfonic acid upon anthraquinone and its derivatives. The hydroxy and amino compounds might be expected to react with this reagent quite readily to give interesting and possibly valuable products.

Sulfonation of Anthracene. Anthracene does not undergo sulfonation in the *meso* (9,10-) positions. The other two rings react similarly to naphthalene in that at temperatures under 100° substitution occurs in the alpha positions while at higher temperatures the beta compounds predominate. From the qualitative information available, anthracene sulfonates at least as easily as does naphthalene and more readily than benzene.

Monosulfonation of anthracene with chlorosulfonic acid or oleum[765] in acetic acid solution gives a mixture of approximately equal amounts[766] of the 1- and 2-sulfonic acids which may be separated by converting to the sodium or barium salts and dissolving the 1-sulfonate in water. The sodium anthracene-2-sulfonate dissolves slightly in hot water while the barium salt is practically insoluble. By monosulfonating with pyridine sulfotrioxide[766,767] in pyridine solution at around 115° there is obtained mostly the 1-sulfonic acid while at 165–170° in high-boiling petroleum as a solvent this reagent gives a 40% yield of sulfonic acids which is chiefly the 2-isomer. In nitrobenzene at ordinary temperatures a 15–20% yield of the 1-sulfonic acid results. The 2-sulfonic acid has been prepared by heating anthracene with 53° Be. sulfuric acid[768a] at 120–135° or with an alkali bisulfate[768a] at 140–150°. The presence of mercury[768b] directs the sulfonation to the 1-position in anthraquinone but not in anthracene.

The data available regarding disulfonation are fragmentary and contradictory. It has been reported[766,769a] that at 100° and at 150–180° a mixture of the 1,5- and 1,8-disulfonic acids is obtained when sulfuric acid is the reagent. It has also been claimed, however,[769b] that by heating anthracene with 53–58° Be. sulfuric acid at 140–145° a mixture of the 2-sulfonic acid and the 2,6- and 2,7-disulfonic acids results, the last-mentioned compound predominating. Since high temperatures favor monosulfonation in the 2-position it is difficult to explain why disulfonation under these conditions should lead to the 1,5- and 1,8-disulfonic acids. The sulfonation of anthracene-2-sulfonyl chloride with 4% oleum has been mentioned [680b] but pure compounds were not isolated. Obviously further investigation is necessary. A number of anthracenesulfonic acids have been prepared by reduction of the corresponding anthraquinone derivatives.[770]

Sulfonation of Anthracene Derivatives. Apparently no simple alkyl derivatives of anthracene have been sulfonated. The 9-benzyl compound with sulfuric acid [771] at 100° gives a sulfonic acid whose structure is unknown. A mixture of products might well be expected in this reaction. 9,10-Dichloroanthracene reacts with chlorosulfonic acid in chloroform at 40°, 100% sulfuric acid [772] at 30°, or with oleum in nitrobenzene [773] to give only the 2-sulfonic acid. The analogous bromine compound behaves similarly with chlorosulfonic acid [772] or with oleum [774] in nitrobenzene below 15°. The presence of a halogen in the 9,10-positions is thus seen to inhibit substitution in the alpha positions in the outside rings. The disulfonic acids obtained from these halogen compounds by the action of oleum [775a] at 100° are undoubtedly the 2,6- and 2,7-compounds. Anthracene-9-carboxylic acid is monosulfonated by sulfuric acid and disulfonated by oleum [775b] at 0°.

Sulfonation of Anthraquinone. The usefulness and limitations of various sulfonation procedures for preparing anthraquinonesulfonic acids have been adequately determined. By suitable reaction conditions it is possible to prepare the two predicted monosulfonic acids and the six disulfonic acids in which substitution has occurred in both rings. It is not possible by any method so far developed to introduce a third sulfo group into the anthraquinone nucleus, oxidation to hydroxy compounds always occurring under conditions where trisulfonation might be expected.[776a] Anthraquinonesulfonic acids have been obtained also by the action of a sulfophthalic anhydride upon benzene followed by ring closure of the benzoylbenzoic acids.[776b]

Perhaps the most interesting feature of the sulfonation reactions of anthraquinone is the effect produced by the presence of a small amount of mercuric sulfate in the sulfonation mixture. Whereas sulfonation in the absence of this catalyst gives approximately 98% beta substitution, with the mercury catalyst high yields of the alpha sulfonic acids result. The conclusion has been reached by the later investigators [777] of the mechanism for this reaction that mercuration of the anthraquinone occurs first, followed by replacement of the mercuri group through the action of sulfur trioxide.

$$C_6H_4(CO)_2C_6H_4 + HgSO_4 \rightarrow C_6H_4(CO)_2C_6H_3HgSO_4H$$

$$C_6H_4(CO)_2C_6H_3HgSO_4H + SO_3 \rightarrow C_6H_4(CO)_2C_6H_3SO_3H + HgSO_4$$

This type of mechanism has already been mentioned in connection with the effect of mercury upon other sulfonation reactions.

In the industrially important reactions involving the oxidation of anthraquinonedisulfonic acids by oleum to various of their hydroxy compounds, boric acid is frequently added to the reaction mixture. This esterifies the hydroxyl groups already present, if any, and combines with the others as they are formed.[778] The molecule is thereby stabilized against decomposition at the temperature necessary for the oxidation to occur and after the reaction the borate esters are readily hydrolyzed.

Anthraquinone is converted into a mixture of mono- and disulfonic acids by heating with sulfuric acid [779a] at 250–260° but the yields are low owing to complex side reactions. More recently [779c] a careful study has been made of the action of concentrations of sulfuric acid ranging from 89.5 to 100% at temperatures from 160° to 230°. The results are given in great detail for which the original should be consulted. The use of oleum [779a, 780] at a lower temperature gives much more satisfactory results. In a careful study [781] of the effect of various factors upon the yield of anthraquinone-2-sulfonic acid the best procedure found involved the addition of 208 g. of anthraquinone to 280 g. of 30% oleum, followed by heating for 6 hours and pouring into water. After separating 65 g. of unchanged anthraquinone, precipitating the sodium sulfonates with sodium chloride solution and recrystallization from water a 64% yield of pure sodium anthraquinone-2-sulfonate was obtained.[782] It has also been found [783a] that monosulfonation can be effected by passing gaseous sulfur trioxide into the reaction mixture at 150–170°. This gives about the same yield of sulfonic acid as is obtained from the use of oleum and the necessity of removing unchanged sulfuric acid is eliminated. There are always some disulfonic acids formed regardless of the sulfonation procedure, the 2,6- and 2,7-compounds resulting in about equal amounts [777b] together with traces of the 1,6- and 1,7-disulfonic acids and hydroxysulfonic acids. The disulfonation practically ceases when the concentration of sulfur trioxide has dropped to 2–3%. The presence of inorganic sulfates decreases the formation of disulfonic acids but a higher temperature is required to effect monosulfonation. Not more than 2–3% of the 1-sulfonic acid is ever formed in the reaction where no catalyst is present. An investigation of the energetics of the anthraquinone sulfonation [783b] has shown that the activation energy is constant within the limits of experimental error for various concentrations of sulfuric acid and amounts to 39.5 kcal. per mole. It is claimed that this value is valid for the gas phase.

Of the many salts of the 2-sulfonic acid which have been investigated the sodium compound is the most characteristic. Because of its appearance it has received the common name of "silver salt."

To effect the monosulfonation of anthraquinone to the 1-sulfonic acid it is best to use 20–25% oleum,[777b] a temperature variously given [781a] as 130–150°, and mercuric sulfate [777b, 784] amounting to 1% of the weight of the anthraquinone. No more oleum should be used than is necessary to furnish 105% of the sulfur trioxide needed [777b] for the sulfonation or disulfonic acids will be formed in large amounts. The presence of more than the 1% of mercuric sulfate specified offers no advantage. In many instances metallic mercury or mercurous sulfate has been added to the mixture as the catalyst but these are rapidly converted to the mercuric sulfate. Small amounts of the sulfates or oxides of various other metals added to the sulfonation mixture have no catalytic effect upon the sulfonation except perhaps vanadium pentoxide which accelerates the reaction somewhat.[777b, 785] A satisfactory procedure for obtaining the potassium anthraquinone-1-sulfonate [781a] is as follows. Heat a mixture of 208 g. of anthraquinone, 200 g. of 20% oleum and 2–4 g. of mercuric oxide or sulfate to 130–135°, add 50 g. of 60% oleum during 1 hour, heat an hour longer and pour into 2 l. of water. Addition of potassium chloride to the aqueous solution gives a 63% yield of potassium monosulfonates of which 97% is the 1-isomer. Some 8% of the disulfonic acids is formed and remains in solution. Separation of the 1-sulfonic acid from the reaction mixture as its sodium salt [786] is also feasible.

It was one time suggested [787] that in all sulfonations of anthraquinone reaction occurs in the 1-position first, followed by rearrangement of the 1-sulfonic acid to the 2-isomer at a high temperature. It was later [788] shown that such a rearrangement does not occur at 180°, a temperature higher than that at which the 2-sulfonic acid is formed from anthraquinone. However, if the 1-sulfonic acid is heated above 200° with 80–90% sulfuric acid [789] in the presence of mercuric sulfate some of the 2-sulfonic acid results, apparently due to hydrolysis of the 1-sulfonic acid to anthraquinone followed by resulfonation. Mercuric sulfate exerts no catalytic effect in sulfonation unless sulfur trioxide is present. Whether it has any effect upon the hydrolysis or not does not seem to be entirely clear.

Analysis of a mixture of the 1- and 2-sulfonic acids may be effected through differences in the solubilities of various salts, or perhaps better, through conversion to the chloroanthraquinones by the action of potassium chlorate and hydrochloric acid [777a] and taking the melting point of the mixture.

For the disulfonation[779, 780, 781a, 782a, 790] of anthraquinone in the absence of a catalyst it is best[777b] to use 110% of the theoretical amount of sulfur trioxide as 40% oleum and heat to 190°. In this manner an 85% yield of the 2,6- and 2,7-disulfonic acids is obtained in the ratio 1 to 1.15. At a lower temperature somewhat more of the 2,7-isomer results. The other reaction products are 1,6- and 1,7-disulfonic acids and hydroxysulfonic acids. Increasing the reaction time or the sulfur trioxide concentration increases the yield of the hydroxy compounds. In the presence of equimolecular amounts of an inorganic sulfate such as sodium sulfate[777b, 791] there is little or no alpha sulfonation or hydroxysulfonic acid formation.

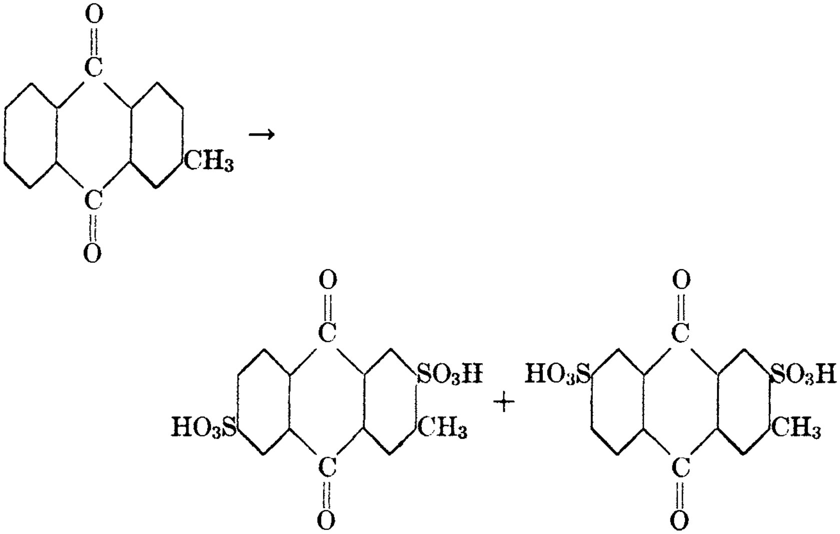
As with the monosulfonic acids, analysis of the 2,6- and 2,7-disulfonic acid mixture may be effected through conversion to the corresponding chlorinated anthraquinones.[777b] The 2,6-disulfonic acid may be separated from the 2-sulfonic acid by precipitating the former as the ammonium salt[792] whereas if sodium sulfate is added to an aqueous solution of these two compounds the sodium 2-sulfonate separates first.[793]

In the disulfonation of anthraquinone in the presence of a mercury catalyst[784a, b, 794] the best[777b, 781a] results are obtained by using enough 40% oleum to furnish 5–10% excess sulfur trioxide and keeping the temperature at 120°. At 130° there is more oxidation but the reaction is complete in 4 to 5 hours instead of in three times as long. It is necessary to heat the reaction mixture slowly so that much of the sulfur trioxide will be used before a temperature is reached at which oxidation becomes important. In this manner are obtained 45–50% of the 1,5-, 24–27% of the 1,8-, 15–21% of the 1,7-, and 5% of the 1,6-disulfonic acids. Separation of the 1,5- and 1,8- compounds from each other may be effected through the free acids or their calcium salts. For further details the work of Lauer[777b] and Fierz-David and coworkers[781a] should be consulted.

The sulfonation of an anthraquinone-1-sulfonate in the *absence* of a catalyst with 40% oleum[777c, 795] gives 68% of the 1,6- and 32% of the 1,7-disulfonic acids while sulfonation of the 2-sulfonic acid in the *presence* of a catalyst (mercuric sulfate)[777c, 784a, 796] gives 41% of the 1,6- and 59% of the 1,7-disulfonic acid. There is thus evidence that the position occupied by a sulfo group in one ring influences considerably the position taken by a group entering the second ring.

There are several instances where sulfuric acid or oleum acts as an oxidizing agent, with or without sulfonation occurring, that give rise to hydroxyanthraquinonesulfonic acids which are of some value as dyestuffs.[784b, 796]

Sulfonation of Alkyl-, Halo-, and Nitroanthraquinones. It was reported by Locher and Fierz[797] that attempts to bring about the direct sulfonation of 2-methylanthraquinone were not successful but Lauer[777b] has shown that with 120% of the theoretical amount of sulfur trioxide as 40% oleum at 150° there results about 30% of the 3,7- and 38% of the 3,6-disulfonic acids.



Many of the known halogen derivatives of the anthraquinonesulfonic acids have been obtained by halogenation. Until quite recently no systematic investigation of the sulfonation of any of the haloanthraquinones was on record. This deficiency has been remedied for a number of the chlorine derivatives by Goldberg.[798] His results are presented in Table XXIII. In these reactions the compound sulfonated was heated at 155–160° for 4 to 5 hours with 2–3 parts of 20% oleum except where one sulfo group was already present in the molecule. Here approximately 6 parts of oleum and a time of 10 to 11 hours were necessary. Under the heading of "catalyst" in the table is indicated whether or not mercuric sulfate was added to the reaction mixture. Several of the chlorine compounds listed in Table XXIII had been sulfonated previously[799,800] but the structures of the resulting sulfonic acids were not determined until Goldberg[798] converted them into the di- and trichloroanthraquinones whose structures were established independently. In addition, it has been found that 2-chloroanthraquinone yields a single monosulfonic acid when sulfonated in

TABLE XXIII

SULFONATION OF CHLOROANTHRAQUINONES

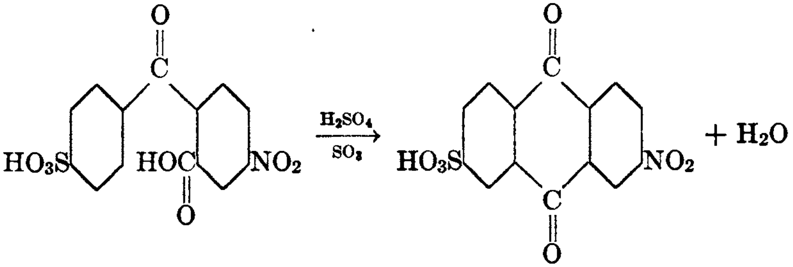
ANTHRAQUINONE DERIVATIVE	CATALYST	POSITION(S) OF SUBSTITUTION
1-Chloro-	−	6- or 7-
	+	5- or 4,5-di-
1-Chloro-5-sulfo-	−	2- or 4-
1-Chloro-6-sulfo-	−	2- or 4-
1-Chloro-7-sulfo-	−	2-
1,2-Dichloro-	−	6- or 7-
1,3-Dichloro-	−	6- or 7-
1,4-Dichloro-	−	6-
1,8-Dichloro-	−	4- or 4,5-di-
1,5-Dichloro-	−	2- or 4- or 2,8-di-
	+	4- or 4,8-di-

the absence of a catalyst and an isomer in the presence of mercuric sulfate.[800] The supposed disulfonic acid of 1,2,3,4-tetrachloroanthraquinone obtained from the tetrachlorobenzoylbenzoic acid[801] should be reinvestigated because in no other analogous case has it been possible to introduce two sulfo groups into the same benzene nucleus of anthraquinone and it seems unlikely that ring closure of the disulfonated compound would be any more feasible.

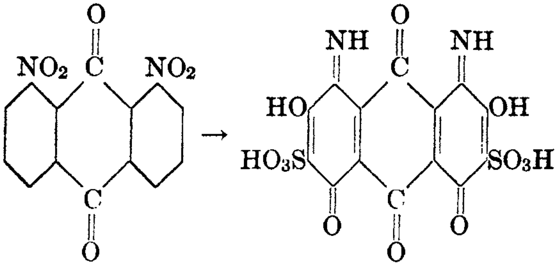
1-Nitroanthraquinone with oleum at 130° in the presence of mercuric sulfate[777c, 802a] yields a mixture of sulfonic acids containing 52% of the 5-, 29% of the 8-, 12% of the 7-, and 7% of the 6-isomer. At 200° sulfuric acid[802b] converts the 1-nitro-6-sulfonic acid into an ether of a dihydroxyaminosulfonic acid. 2-Nitroanthraquinone-7-sulfonic

$$O_2NC_6H_3(CO)_2C_6H_3SO_3H \xrightarrow{H_2SO_4} O[C_{14}H_4O_2(NH_2)(OH)SO_3H]_2$$

acid has been prepared only by ring closure of the benzoylbenzoic acid.[802c]



The 1,5- and 1,8-dinitroanthraquinones with sulfur, oleum, and boric acid[803] at 120–130° give complex quinone type compounds.



Sulfonation of Aldehydo- and Carboxyanthraquinones. 1-Chloro-2-anthraquinonealdehyde has been sulfonated[804] but the position of the sulfo group is not known. This is also true for the compound obtained from 2-anthraquinonecarboxylic acid and 40% oleum.[805]

Sulfonation of Hydroxyanthraquinones. It is somewhat surprising to find that oleum at temperatures usually well above 100° is necessary to sulfonate compounds containing phenolic groups, but this is true for the hydroxyanthraquinones. Another unusual feature of these sulfonations is that substitution invariably occurs *ortho* to hydroxyl rather than *para* as it does in benzene derivatives. As with anthraquinone itself, sulfonation tends to occur in beta rather than alpha positions. Practically all the data available concerning the reactions come from the older patent literature, the major part of the technical interest in the resulting hydroxy sulfonic acids finding expression in the decade following 1900.

The essential data of the sulfonations are presented in Table XXIV. The reagent in each case is oleum, the percentage of sulfur trioxide being given in the second column. Wherever mercuric sulfate or boric acid was added to the reaction mixture this is also indicated.

In addition, there are several instances where sulfonation and oxidation occur in the same reaction mixture. Thus alizarin when heated with oleum followed by treatment with sulfuric acid[806] yields a 1,2,5-trihydroxysulfonic acid, and 1-hydroxyanthraquinone-8-sulfonic acid with 20% oleum, boric acid, and mercuric oxide[807] gives a 1,4-dihydroxyanthraquinonedisulfonic acid. The sulfonation of 1-phenoxyanthraquinone-6-sulfonyl chloride with 4% oleum has been mentioned.[580b]

Sulfonation of Aminoanthraquinones. As in the sulfonation of the hydroxy compounds the sulfonation of the aminoanthraquinones leads to *ortho* substitution. Thus 1-aminoanthraquinone with oleum and sodium sulfate,[808a] with chlorosulfonic acid,[808b] or with two or more molecular equivalents of sodium bisulfate[809] at 210–240° is converted into the 2-sulfonic acid, and 2-aminoanthraquinone with oleum to

TABLE XXIV

Reaction of Oleum with Hydroxyanthraquinones

Anthraquinone Derivative	Reagent (% SO_3) and Reference	Reaction Temperature	Position(s) of Sulfo Group(s)
1-Hydroxy-	20%[1, 2]	100 or 150°	2-
2-Hydroxy-	20%[2, 3a]	120 or 150°	3-
1,2-Dihydroxy-(alizarin)	20–40%[3]	120–140°	3- and 4-
	20–40%[4]	130–170°	3,6- and 3,7-di-
	20%, mercury catalyst	110°	3,5-di- and 3,8-di-
1,3-Dihydroxy-	20%[2]	130°	2- (?)
1,4-Dihydroxy-	20%[2, 16]	140°	2- (?) or 6-
1,5-Dihydroxy-	20%,[6] 3 parts	100–120°	2,6-di-
	25%,[7] 10 parts	120°	2,4,6,8-tetra-
1,8-Dihydroxy-	20%[8]	100–120°	2,7-di-
	25%[7]	120°	2,4,5,7-tetra-
2,6-Dihydroxy-	10–20%[2, 9]	100–120°	3,7-di-
2,7-Dihydroxy-	10–20%[10]	100–120°	3,6-di- (?)
1,2,4-Trihydroxy-	20%[11]	100°	3-
1,2,4-Trihydroxy-8-sulfo-	20%[12]	....	3-
1,2,6-Trihydroxy-	10–20%[13]	120–150°	3- (?)
1,2,7-Trihydroxy-	10–20%[13]	120–150°	3- (?)
1,4,5-Trihydroxy-	30%,[14] boric acid	130°	6-
1,3,5,7-Tetrahydroxy-	20%[15]	115–120°	2,6-di-
1,2,4,8-Tetrahydroxy-	30%,[14] boric acid	130°	3-

---

[1] Bayer and Co., German pat., 127,438, *Chem. Zentr.*, I, 329 (1902).

[2] Georgievics, *Chem. Zentr.*, I, 1515 (1905).

[3] (*a*) von Perger, *J. prakt. Chem.*, [2] **18**, 179 (1878). (*b*) Graebe and Liebermann, *Ann.*, **160**, 131 (1871).

[4] Bayer and Co., German pat., 56,952, *Frdl.*, **3**, 270.

[5] Wedekind, German pat., 210,863, *Chem. Zentr.*, II, 243 (1909).

[6] Bayer and Co., German pat., 96,364, *ibid.*, I, 1255 (1898); see also Rogers, U. S. pat., 1,924,166, *C.A.*, **27**, 5340 (1933).

[7] Bayer and Co., German pat., 141,296, *Chem. Zentr.*, I, 1163 (1903); see also Badische Anilin- und Sodafabrik, German pat., 108,459, *Frdl.*, **5**, 274.

[8] Wölbling, *Ber.*, **36**, 2941 (1903); Bayer and Co., German pat., 100,136, *Chem. Zentr.*, I, 655 (1899).

[9] Höchster Farbwerke, German pat., 99,874, *ibid.*, I, 464 (1899); Wedekind and Co., German pat., 244,372, *ibid.*, I, 962 (1912).

[10] Höchster Farbwerke, German pat., 99,612, *ibid.*, I, 399 (1899).

[11] Bayer and Co., German pat., 89,027, *Frdl.*, **4**, 324.

[12] Bayer and Co., German pat., 172,688, *Chem. Zentr.*, II, 646 (1906).

[13] Höchster Farbwerke, German pat., 86,151, *Frdl.*, **4**, 280.

[14] Bayer and Co., German pat., 165,860, *Chem. Zentr.*, I, 520 (1906).

[15] Heller, *Ber.*, **46**, 2708 (1913); Höchster Farbwerke, German pat., 70,803, *Frdl.*, **3**, 242.

[16] Mildner, U. S. pat., 1,879,390, *C.A.*, **27**, 1010 (1933).

which boric acid may be added[810] sulfonates in the 3-position. 1-Aminoanthraquinone and its N-methyl derivative in the presence of boric acid with 80% oleum[811] at 30–35° are both oxidized and sulfonated.

Most of the aminoanthraquinones which have been sulfonated also contain hydroxyl groups. The results obtained with these compounds are listed in Table XXV. The percentage in the second column refers to the sulfur trioxide content of the oleum used.

TABLE XXV

SULFONATION OF AMINOHYDROXYANTHRAQUINONES

Anthraquinone Derivative	Reagent (% SO_3) and Reference	Reaction Temperature	Position of Sulfo Group
2-Hydroxy-1-amino-	20%[1]	130°	3- (?)
4-Hydroxy-1-amino-	60%,[2] boric acid	110–120°	6-
1-Hydroxy-2-amino-	20%[1]	115°	3-
1,2-Dihydroxy-4-amino-	20-40%,[3] 10 parts; boric acid	100–120°	3-
1,4-Di-*p*-toluenesulfonamido-5-hydroxy-	20%,[4] boric acid	30–40°	6-
1,5-Dihydroxy-4,8-diamino-	20%,[5] boric acid	100–120°	2-
1,8-Dihydroxy-4,5-diamino-	20%,[6] boric acid	100–120°	2-

[1] von Perger, *J. prakt. Chem.*, [2] **18**, 183 (1878).
[2] Bayer and Co., German pat., 161,035, *Chem. Zentr.*, II, 283 (1905).
[3] Höchster Farbwerke, German pat., 82,938, *Frdl.*, **4**, 329; Schultz and Eber, *J. prakt. Chem.*, [2] **74**, 293 (1906).
[4] Bayer and Co., German pat., 170,113, *Chem. Zentr.*, I, 1723 (1906).
[5] Bayer and Co., German pat., 117,892, *ibid.*, I, 487 (1901).
[6] Bayer and Co., German pat., 117,893, *ibid.*, I, 550 (1901).

The sulfonation of 1-hydroxy-4-*p*-tolylaminoanthraquinone with sulfuric acid[812] at 70–80° introduces the substituent in the 2-position. On the other hand, arylaminoanthraquinones not having the hydroxyl group sulfonate in the aryl group.[812, 813]

SULFONATION OF PHENANTHRENE AND ITS DERIVATIVES

The investigation of the sulfonation reactions of phenanthrene and its substitution products has encountered many difficulties, not only because of the number of the isomeric sulfonic acids formed but also because of the tendency of the metal sulfonates to form supersaturated solutions; this behavior renders separation by fractional crystallization very tedious if not impossible. In no instance has the preparation of a pure disulfonic acid been accomplished, although the nature of the compounds in the mixture has been ascertained indirectly. Apparently no attempt has been made to separate the phenanthrenesulfonic acids by way of their acid chlorides. It is possible that this might offer some advantages.

Sulfonation of Phenanthrene. Treating phenanthrene with sulfuric acid[814] at 100° or below produces a mixture of the 2-, 3-, and 9-sulfonic acids. At somewhat higher temperatures (120–125°) the 9-sulfonic acid disappears from the reaction mixture, probably because of rearrangement[815] to the other isomers. This is rendered more reasonable by the fact that heating the ammonium phenanthrene-9-sulfonate at 250–260° gives a mixture of phenanthrene, ammonium phenanthrene-2-sulfonate, and a disulfonate.[814c] At 60° and probably at other temperatures some of the 1-sulfonic acid is formed.[814d] The monosulfonic acids are always accompanied by considerable amounts of disulfonation products which may be decreased by using 67–80% sulfuric acid[816] instead of the concentrated reagent; this, however, necessitates a prolonged reaction time. From fractional crystallization of the ferrous and potassium salts of the monosulfonates obtained by sulfonation at 60°, Fieser[814d] was able to separate 18% yields of the 2- and 3-sulfonic acids, 13% of the 9-, and 8% of the 1-isomers. These acids are all readily identified by means of their *p*-toluidine salts.

Monosulfonation has also been brought about by the action of an equimolecular quantity of chlorosulfonic acid in boiling chloroform;[817] only the 2- and 3-sulfonic acids were isolated from the reaction product, an 85% yield of the mixed lead sulfonates being obtained.

The disulfonation of phenanthrene[814a, 818] produces a complex mixture of acids which may contain as many as twelve isomers.[819] Even the mixtures obtained by the further sulfonation of the pure 2- and 3-sulfonic acids have so far resisted all attempts at separation. By conversion of the disulfonates into the corresponding phenanthradiols and fractionating the acetates of these, evidence was obtained as to the composition of the original mixtures. Assuming no rearrangements occur during the alkali fusions both the 2- and 3-sulfonic acids substitute in the 6-, 7-, and 8-positions, yielding a total of five isomers. The 1- and 9-sulfonic acids have not been further sulfonated, and no sulfonic acid is known with a sulfo group in the 4-position.

Sulfonation of Phenanthrene Derivatives. When 1-methyl-7-isopropylphenanthrene (retene) is heated with an equal weight of sulfuric acid at 100° for 5 minutes the so-called "A"-sulfonic acid results, while at 200° for 2 minutes there is formed the "B" isomer.[819b] The latter is the 6-isomer and the former is a mixture of the 2- and 6-compounds.[819c] Upon standing with cold oleum or sulfuric acid [820] for several weeks a disulfonic acid results. Undoubtedly some other procedure would be much more convenient. Not enough is known concerning the directive influence of alkyl groups in the phenanthrene nucleus to hazard a guess as to the structure of the reaction product; however, one might expect more than one disulfonic acid to result from this reaction. At 100° a trisulfonic acid is produced.[820] From the action of nitric acid upon a solution of retene in 20% oleum [821] there results a nitrosulfonic acid.

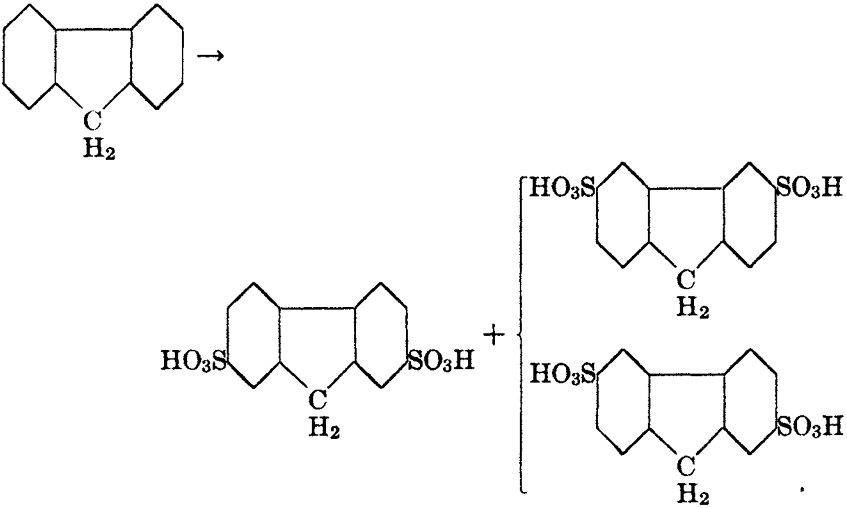
In contrast to phenanthrene the 9-chloro- or 9-bromo- compound with sulfuric acid [822] at 100° gives as high as 65–75% yields of one sulfonic acid, the 3-(or 6-) derivative. That it is the 3- or 6-compound follows from its reduction with zinc and ammonia to the phenanthrene-3-sulfonic acid. The bromosulfonic acid under the name of I-10-bromophenanthrene-3(or 6-)-sulfonic acid has been utilized in many investigations because of the interesting behavior of its aqueous solutions. Dilute solutions behave like those of any ordinary electrolyte while one which is more concentrated exhibits colloidal or anisotropic properties, depending upon the temperature and the exact concentration employed. The change from colloidal to liquid crystal form occurs at a definite temperature for a solution of a given concentration.[823] The action of light [824] upon an aqueous solution of the acid results in a viscosity change that was ascribed to the formation of a new compound of unknown structure.

10-Chloro-9-hydroxyphenanthrene has been disulfonated by heating with sulfuric acid [825] at 100°.

2-Bromophenanthrenequinone when heated with 4% oleum at 100° for 24 hours yields a monosulfonic acid while with 35% oleum at room temperature [826] after two days disulfonation is complete. 2-Hydroxyphenanthrenequinone has also been sulfonated.[827] The 2,7-diamino- and dianilinophenanthrenequinones yield sulfonic acids which are mordant dyes.[827]

Sulfonation of Miscellaneous Polycyclic Compounds

The colorations accompanying the sulfonation of high-molecular-weight hydrocarbons are believed [828] to be caused by the formation of sulfur trioxide complexes. Through the action of sulfuric acid in acetic anhydride, or of chlorosulfonic acid alone [829] or in chloroform solution [830] fluorene yields the 2-sulfonic acid.[831] Further sulfonation with chlorosulfonic acid or with four parts of sulfuric acid at 100° produces the 2,7-disulfonic acid; [832] in this last reaction two other disulfonic acids also result. The structure of the chief product has been determined by fusion with alkali.[829] The probable structures of the two by-products are also indicated in the equation.



The sulfonic acid from 2,7-dibromofluorene and chlorosulfonic acid[830] is quite probably the 3-compound. Its structure has not been determined, however.

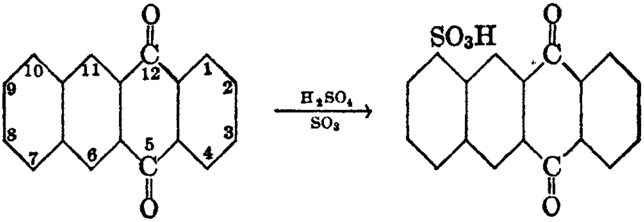
By heating fluorenone to 250–260° with sulfuric acid[833] sulfonation is effected in the 2,7-positions as with fluorene.

What might be considered as the next higher homolog of fluorene, 9,10-dihydrophenanthrene, undergoes disulfonation readily when warmed with sulfuric acid[834] to 80°. Neither this compound nor the ones obtained from "abietene"[835] and "abietanes"[836] have had their structures determined.

Fluoranthene (idryl) when warmed with two parts of sulfuric acid[837] at 100° yields a disulfonic acid. This is also true of pyrene[838] and of 1,3,5-triphenylbenzene when pyrosulfuric acid[839a] is the sulfonating agent. The sulfonation of pyrene[839b,c] with chlorosulfonic acid in carbon tetrachloride or tetrachloroethylene at 0–5° gives a good yield of the light yellow 3-sulfonic acid. Various derivatives of the acid were prepared. Hydroxy derivatives of fluoranthene- and pyrenesulfonic acids have also been mentioned.[839d] By heating 2,2′-binaphthyl to 200° with one-fifth of its weight of sulfuric acid two monosulfonic acids result while with oleum a tetrasulfonic acid is formed.[840a] When 2,2′-dihydroxy-1,1′-binaphthyl is heated with 96% sulfuric acid a mixture of the 6-sulfonic acid and the 6,6′-disulfonic acid results.[840b]

The disulfonic acid is identical with that obtained by oxidation of 2-naphthol-6-sulfonic acid with ferric chloride. Decacyclene sulfonates to a trisulfonic acid which is an acid dye.[841]

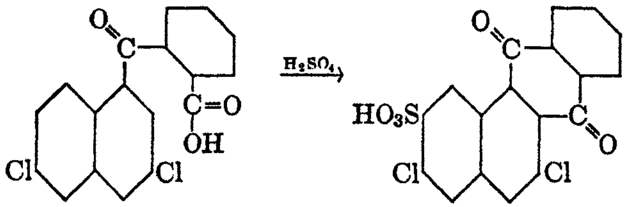
Naphthacenequinone when treated with 18% oleum at 100° is converted into a sulfonic acid probably containing the sulfo group in the ring not attached to the keto linkages.[842a]



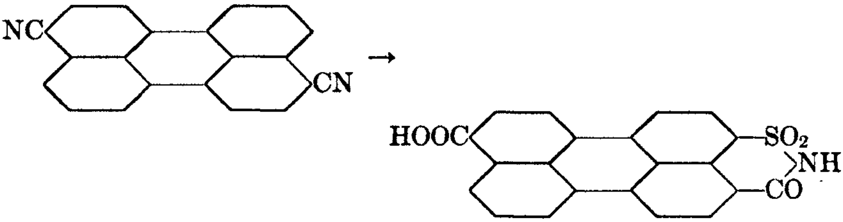
The 11-hydroxy compound when treated with a large excess of sulfuric acid in the presence of boric acid at 140° followed by oleum at a high temperature is both oxidized and sulfonated,[843a] a 6,11-dihydroxysulfonic acid resulting. Under less vigorous conditions only sulfonation may occur.

The monosulfonation of 1,9-benzanthrone has been investigated in detail.[842b] The activation energy of this reaction is 27.4 kcal. per mole, a value that holds for all concentrations and for the gaseous state. Benzanthrone reacts completely with 30% oleum at 150° in 6 hours to give 81% of the α-sulfonic acid and 19% of the β-isomer, separated as their barium salts.[842c] The sulfonation of *ms*-benzanthrone has recently been studied by Pritchard and Simonsen.[842d]

1,2-Benzanthraquinone has been monosulfonated by treatment with 20% oleum [844] to give the 4′-sulfonic acid. The sulfonation occurs more readily than for anthraquinone, since reaction occurs with 95% sulfuric acid at 100°. High and low temperatures give different sulfonic acids but the sulfo group is still in the "benzo" nucleus.[843b] 2-(1,5-Dihydroxy-2-naphthoyl)-benzoic acid undergoes ring closure and sulfonation when treated with sulfuric acid and boric acid.[845] Analogous reactions occur when 2-(3,6-dichloro-1-naphthoyl)-benzoic acid is warmed with sulfuric acid [846] at 100°



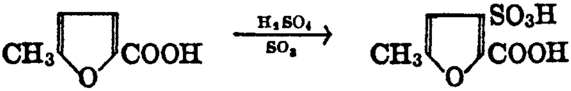
A chrysenequinonedisulfonic acid has been obtained by sulfonation of the quinone.[847a] The preparation of amino, hydroxy,[839d] and nitrochrysenesulfonic acids through sulfonation reactions has been patented.[847b,c] A dicyanoperylene and the corresponding acid when warmed with sulfuric acid yield an imide and anhydride respectively.[848]



Sulfonation of Heterocyclic Compounds

A considerable number of compounds of the aromatic type containing one or more hetero atoms have been sulfonated.

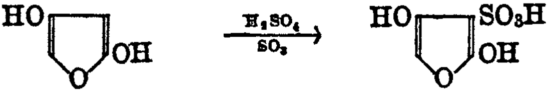
Sulfonation of Furan Derivatives. Although furan is unstable in the presence of even dilute acids, furoic acid is converted into a sulfonic acid through the action of oleum at room temperature without extensive decomposition,[849] substitution occurring in the 5-position. If this position is occupied as in 5-methylfuroic acid[850] sulfonation presumably occurs in the 3-position.



Interestingly enough it was not found possible to prepare a compound of the saccharin type from this last sulfonic acid, and more recently[850c] doubt has been expressed as to this structure and that of the other sulfonated 5-substituted furoic acids.

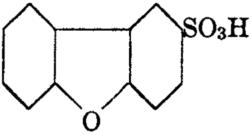
The halogen derivatives of furoic acid sulfonate when the 3- or 5-position is unoccupied. Thus 3-chlorofuroic acid reacts in the 5-position, the 5-chloro compound yields the 3-sulfonic acid, the 3,4-dichloro compound the 5-sulfonic acid, and the 4,5-dichloro compound the 3-sulfonic acid.[851] The corresponding bromine derivatives behave similarly[849b] while the 3,5-dibromofuroic acid does not sulfonate in 24 hours' contact with oleum. After many days, however, decomposition to bromomaleic acid becomes apparent. Tribromofuroic acid in an analogous manner gives rise to dibromomaleic acid.

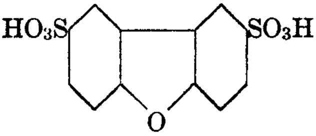
A compound known as tetronic acid which in its dienol form is a furan derivative forms a sulfonic acid when warmed with oleum.[852]



Phthalide may be looked upon as a ketodihydrobenzofuran. With 20% oleum [853] at 100° it is converted into a sulfonic acid of unknown structure.

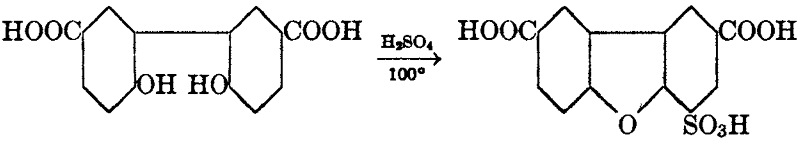
Since dibenzofuran has no replaceable hydrogens on the furan ring the substitution reactions of this compound are those of a benzene derivative. By treating with an equimolecular amount of chlorosulfonic acid [854] in carbon tetrachloride at 25° for 1 hour an 89% yield of the sulfonic acid (as the sodium salt) results. It was claimed that the free acid was obtained by acidifying a solution of the sodium salt and cooling. Inasmuch as the resulting product melted above 300° it is doubtful if the acid was obtained. The structure of the sulfonation product was shown to be that indicated by converting it into the mercuri chloride by way of the sulfonyl chloride and sulfinic acid. In a similar way the disulfonic acid obtained by the action of sulfuric acid on dibenzofuran [855] was shown to be the 2,8-compound. It is possible that the mono and disulfonic acids obtained by the action of oleum [856] upon 2,2′-dihydroxybiphenyl are identical with the foregoing.





A sulfonic acid of undetermined structure results from sulfonation of 3-nitrobenzofuran.[857] The hexanitrodibenzofuransulfonic acid of Mailhe [858a] does not exist.[858b]

Sulfuric acid acts upon 2,2′-dihydroxybiphenyl-5,5′-dicarboxylic acid [859] to give a sulfonic acid of the corresponding dibenzofuran.



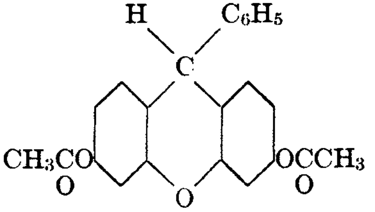
The dinaphthofurans obtained from α- and β-naphthol react with either sulfuric [860] or chlorosulfonic [861] acid to give tetrasulfonic acids.

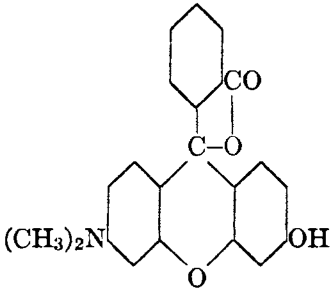
Sulfonation of Benzopyran Derivatives. It was shown by Perkin [862] that 2-ketobenzopyran (coumarin) and its 3-methyl homolog react with oleum at 100° to give monosulfonic acids, and the former at 160° yields a disulfonic acid. More recently [863] it has been shown that the monosulfonic acids are the 6-compounds and the disulfonic acid is the 3,6-product. 6-Nitrocoumarin also sulfonates in the 3-position. 4-Methyl-, 4,7-dimethyl-, 3,4,7-trimethyl-, and 4-methyl-7-methoxycoumarin all sulfonate in the 6-position,[864] while 4,6-dimethylcoumarin gives the 8-sulfonic acid. Chromones were found to sulfonate with much more difficulty than coumarin derivatives. 2,3-Dimethylchromone sulfonates in the 6-position.

3-Phenylcoumarin has been converted into mono and disulfonic acids by the action of oleum,[865] and 3,4-benzocoumarin with sulfuric acid[866] at 100° yields a disulfonic acid. 3,4-Dihydrobenzopyran (chroman) with sulfuric acid[867] gives a sulfonic acid which is probably the 6-isomer.

A number of naturally occurring flavone derivatives have been sulfonated[868] but the structures of the resulting compounds were not determined.

Sulfonation of Xanthene Derivatives. Little is known concerning sulfonic acids of this series. Upon warming xanthone with oleum[869] a disulfonic acid is formed. Monosulfonic acids have been obtained from the xanthene derivatives[870] whose formulas are shown.





Sulfonation of Thiophene and Thionaphthene. The thiophene nucleus sulfonates with ease, particularly when a position adjacent to the sulfur is open. Steinkopf and co-workers have prepared a number of mono and disulfonation products of thiophene and its halogen and alkyl derivatives. The reactions are summarized in Table XXVI.

The sulfonation of thionaphthene gives a mono and then a disulfonic acid; their structures are unknown.[871a] Dibenzothiophene[871b] sulfonates successively in the 3- and 6-positions.

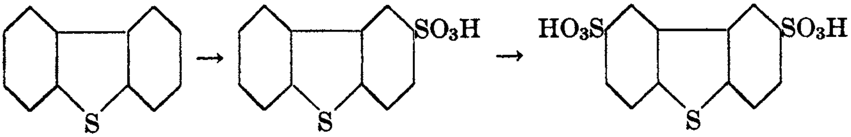


TABLE XXVI

SULFONATION OF THIOPHENE DERIVATIVES

Compound Sulfonated	Reagent and Reference	Reaction Conditions	Sulfonic Acid Formed
Thiophene substituent			
None	ClSO$_3$H[1]	−10°	2-SO$_2$Cl
2-Sulfonyl chloride	7% oleum[1]	20–30°	2,4- and 2,5-
2-Chloro-	ClSO$_3$H[2]	−10°	5-SO$_2$Cl
2,3-Dichloro-	ClSO$_3$H[2]	......	5-SO$_2$Cl
2,3,4-Trichloro-	ClSO$_3$H[2]	......	5-SO$_2$Cl
2,3,5-Trichloro-	ClSO$_3$H[2]	......	4-SO$_2$Cl
2-Bromo-	ClSO$_3$H[3]	Cold	5-SO$_2$Cl, then 3,5-di-
2,3-Dibromo-	ClSO$_3$H[3]	Cold	5-SO$_2$Cl
2,4-Dibromo-	ClSO$_3$H[3]	Cold	5-SO$_2$Cl
	33% Oleum[3]	20–30°	3,5-di
2,5-Dibromo-	Oleum[3]	......	3,4-Anhydride
3,4-Dibromo-	ClSO$_3$H[3]	......	2-SO$_2$Cl
	33% Oleum	......	2,5-di
2-Iodo-	ClSO$_3$H[3]	−15°	5-SO$_2$Cl and 2-C$_4$H$_3$S(SO$_2$Cl)
2-Iodo-5-chlorosulfonyl-	33% Oleum[3]	< 35°	3,5-di
2,4-Dimethyl-	33% Oleum[3]	......	3,5-di
2,5-Dimethyl-	33% Oleum[3]	......	3,4-Anhydride
2-Methyl-5-bromo-	Oleum[4]	......	3,4-Anhydride

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[1] Steinkopf and Höpner, *Ann.*, **501**, 174 (1933).

[2] Steinkopf and Köhler, *Ann.*, **532**, 250 (1937).

[3] Steinkopf, Jacob, and Penz, *Ann.*, **512**, 136 (1934).

[4] Steinkopf, *Ann.*, **518**, 281 (1935).

It has been mentioned under sulfonation reactions of biphenyl that this hydrocarbon and its derivatives give dibenzothiophene dioxide sulfonic acids under some conditions.

Sulfonation of Derivatives of Benzopyrrole, Phthalocyanine, and Carbazole. The pyrrole nucleus, like that of furan, is decomposed readily even by dilute acids. The presence of the carboxyl group results in stabilization but apparently the resulting acids have not been sulfonated. This is also true for benzopyrrole (indole) but the sulfonic acids of isatin and indigo are well known. Carbazole because of the presence of two benzene rings reacts toward sulfonating agents more like diphenylamine than a pyrrole derivative.

The sulfonation of *α*-*n*-heptadecenylindole and alkylindoles has been described [872a] but the nature of the products is uncertain. These compounds are wetting agents.

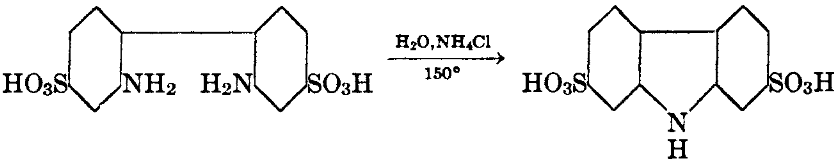
Isatin reacts with 20% oleum [872b] at 100° to give the 5-sulfonic acid. Since indigo carmine on oxidation also yields this acid sulfonation of indigo occurs in the same position as for isatin.

The sulfonation of indigo has been studied by many investigators.[873] This has been due to its availability, the interest in the dyeing properties of the resulting sulfonic acids, and the fact that sulfonation is a step in one procedure for the analysis of indigo. Shaking one part of indigo with twenty parts of sulfuric acid and ten parts of sand yields the monosulfonic acid.[874a] This is soluble in hot water but gives a very insoluble potassium salt. With this same excess of sulfuric acid at 100° there results the disulfonic acid,[874b] whereas at 120–130° a much smaller quantity of acid suffices.[875] The sulfo groups have been shown to be *para* to the nitrogens.[876] Warming 10 g. of indigo with 100 g. of 15% oleum at 45–55° yields a trisulfonic acid [874a] while with 20–50% oleum at 100–110° a tetrasulfonic acid results.[874a, 877] The potassium salt separates from water as red crystals. The positions of the last two sulfonic acid groups are known since the isatindisulfonic acid formed upon oxidation yields with bromine 5,7-dibromoisatin and 2,4,6-tribromoaniline.[878] Indigosulfonic acids with the sulfo group *meta* to nitrogen have been made by other methods.[879] A number of chlorine-containing indigosulfonic acids have been made by the action of 60% oleum [880a] upon chloroarylglycines, followed by oxidation.

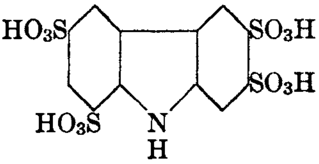
Phthalocyanines may be regarded as benzopyrrole derivatives. Heating with chlorosulfonic acid converts them into sulfonyl chlorides.[880b]

Only one of the various sulfonic acids obtained by the sulfonation of carbazole or its derivatives seems to have had its structure unequivocally established. In other instances reasonable surmises may be made [881] as to the positions occupied by the sulfo groups. Carbazole is little affected by sulfuric acid at room temperature [882] but at 70–75° treating 20 g. of carbazole with 12.5 g. of acid [882, 883] produces a mixture of di and trisulfonic acids together with unchanged carbazole. No monosulfonic acid was isolated, probably because the excess sulfuric acid was removed as barium sulfate, the barium salt of the monosulfonic acid also being little soluble in water. The preparation of carbazole-3-sulfonic acid [884a] may be effected satisfactorily by the use of 100% sulfuric acid [884b] at 100°, by chlorosulfonic acid in nitrobenzene,[885] or by 20% oleum in the same solvent.[886] Isolation of the free sulfonic acid is best accomplished by precipitation from its aqueous solution by hydrochloric acid. The sodium salt is readily soluble in hot water but only slightly so in the cold.

By variation of the reaction conditions at least three carbazoledisulfonic acids are obtainable.[887a] Carbazole-2,7-disulfonic acid has been made [887b] by heating 3,3′-diaminobiphenyl-5,5′-disulfonic acid with a salt solution to about 150° but this has not been compared with the sulfonation products of carbazole.



Judging by the reported difference in the solubilities of their potassium salts there are two carbazoletrisulfonic acids; one is produced by the action of a mixture of sulfuric acid and oleum,[888] the other with sulfuric acid in the presence of a mercury catalyst.[886] Sulfonation of carbazole with oleum produces a tetrasulfonic acid.[889] In more recent patents [890a] this has been assigned the accompanying structural formula.



The 9-methyl- and 9-ethylcarbazoles have been sulfonated by methods already described for carbazole itself.[885, 886] A 9-*n*-butylcarbazolesulfonic acid has also been described.[890b] The sulfo group probably enters *para* to nitrogen in each instance.

A number of nitrocarbazoles have been converted into sulfonic acids. Monosulfonation of 3-nitrocarbazole has been effected by chlorosulfonic acid in nitrobenzene,[891] and disulfonation by 67% sulfuric acid [887] at 130–140°. 3,6-Dinitrocarbazole gives rise to two mono- and two disulfonic acids.[892] Tri and tetranitrocarbazole sulfonic acids have been obtained by nitration of the sulfonic acids.[882, 886] 3-Nitro-9-methylcarbazole has been sulfonated by chlorosulfonic acid in nitrobenzene.[891]

Sulfonation of Pyridine. The introduction of a sulfo group into the pyridine nucleus occurs with great difficulty. By refluxing a sulfuric acid-pyridine mixture 30–40 hours, or by heating in a sealed tube for a shorter time [893] a small yield of the 3-sulfonic acid results. An improved procedure is to distil a pyridine-100% sulfuric acid mixture slowly.[894] According to more recent work [895] this gives a 13% yield of the 3-sulfonic acid provided 5–10% oleum is used as the sulfonating agent.

While no reaction occurs below 300° without a catalyst, in the presence of mercuric sulfate[896] at 225° sulfonation occurs in the 3-position, whereas at 350° the 2-sulfonic acid is also present[895] to the extent of about 1%. Separation of the two products was found to be very difficult, only the 3-isomer being obtained in a pure state. Vanadium sulfate did not appreciably catalyze the sulfonation. Heating piperidine[897c] with sulfuric acid produces some pyridine-3,5-disulfonic acid in addition to the 3-sulfonic acid.

Heating 3-hydroxypyridine with five times its weight of 100% sulfuric acid and a vanadyl sulfate catalyst produces 3-hydroxypyridine-2-sulfonic acid,[897a] also prepared by diazotization of the amino compound.

2-Aminopyridine reacts with 10% oleum[897b,898a] to give what is probably the 5-sulfonic acid. Chlorosulfonic acid sulfonates 3-aminopyridine[898b] in the 2- or 6-position as the resulting aminosulfonic acid may be converted into pyridine-2-sulfonic acid by loss of the amino group.

Nitrogen-substituted pyridones react with chlorosulfonic acid[899] to produce 5-sulfonic acids.

Sulfonation of Quinoline and Derivatives. As might be expected from the difficulty encountered in sulfonating pyridine, in quinoline substitution reactions the benzene nucleus is the one attacked. Sulfuric acid does not react with quinoline at 100°, sulfonation beginning at 220–230° with formation of the 8-sulfonic acid.[900] At 300° a good yield of the 6-sulfonic acid results. As might be expected from these observations, the 8-sulfonic acid rearranges to the 6-isomer at 300°.

Heating quinoline with 10–20% oleum[901] gives a mixture of the 5-, 7-, and 8-sulfonic acids at 125–130° whereas at 170–180° only the 5- and 8-compounds remain; more than one-half of the mixture is the latter.[902] By long heating of the monosulfonic acids with oleum in a sealed tube disulfonic acids result.[903]

8-Methylquinoline reacts with oleum to yield the 5-sulfonic acid while the 6-methyl compound is converted into the 8-sulfonic acid.[904]

When 8-hydroxyquinoline stands with oleum at a low temperature[902,905] sulfonation occurs in the 5-position. The same is true for 8-ethoxyquinoline.[902] The 7-iodo derivative of the hydroxysulfonic acid has found use in chemotherapy under the name of Yatren and the ethoxysulfonic acid is reported as useful in ophthalmology.

5-Chloro-8-hydroxyquinoline is sulfonated by oleum,[906] probably in the 7-position.

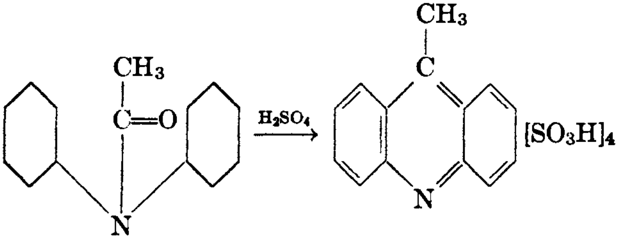
More recently[907] the sulfonation of 5-, 6-, 7-, and 8-aminoquinolines has been reported; the substitutions occurred only in the benzene ring. The reagent was 25–40% oleum. The results are summarized below.

TABLE XXVII

COMPOUND	SULFONIC ACID(S)
5-Aminoquinoline	6-, 8-, and 6,8-di
6-Aminoquinoline	5-
7-Aminoquinoline	8-
8-Aminoquinoline	5-, and 5,7-di

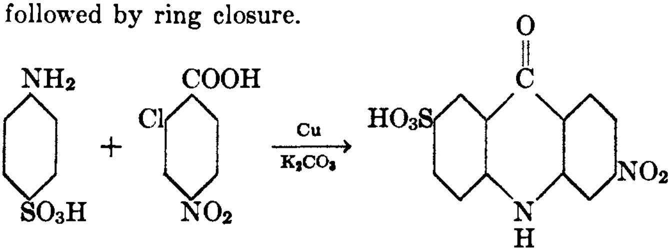
Treatment of 7,8-benzoquinoline with cold oleum[908a] results in formation of what is probably the benzo[h]quinoline-5- or 7-sulfonic acid. The 7-sulfonic acid has been converted into a disulfonic acid of unknown structure.[908b]

Sulfonation of Derivatives of Acridine. Acridine has apparently not been sulfonated. However, the action of sulfuric acid upon N-acetyldiphenylamine yields a methylacridinetetrasulfonic acid.[909] Quite possibly ring closure occurs before sulfonation. 4-Hydroxyacridine

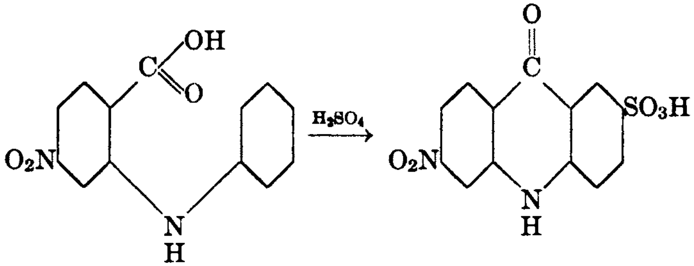


with oleum (5%) at 8° for 24 hours[905b] yields the 1-sulfonic acid. By heating a solution of acridone or phenylanthranilic acid in sulfuric acid[910a] at 50–100° for one-half hour a high yield of acridone-2-sulfonic acid may be obtained. This is convertible into various derivatives of acridine.

The action of 20% oleum upon 6-nitroacridone[910b] gives 97% of the 2-sulfonic acid, isolated as the sodium salt. The structure of the acid follows from its synthesis by condensation of 2-chloro-4-nitrobenzoic acid with sulfanilic acid in the presence of copper and potassium carbonate followed by ring closure.



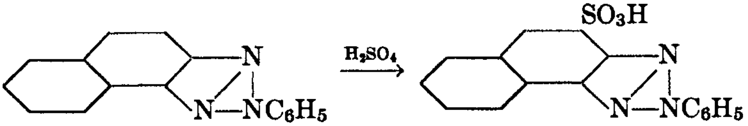
It is also obtained by sulfonation of 5-nitrodiphenylamine-2-carboxylic acid.



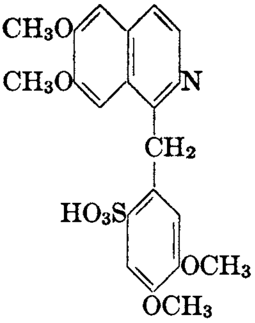
Sulfonation of Imidazoles. Imidazole sulfonates with great difficulty; however, by the use of 50–60% oleum[911a] at 160° an 83% yield of what is the 4- (or 5) sulfonic acid results.[911b] 2-Methylimidazole[912] and the 4- (or 5) isomer[911b] have also been sulfonated. Small quantities of disulfonic acids were obtained from both imidazole and the 2-methyl homolog.

Sulfonation of Isoxazoles, Oxazoles, and Thiazoles. The action of excess chlorosulfonic acid at the boiling point upon 3- and 5-methylisoxazoles gives a mixture in each instance of the 4-sulfonyl chloride and sulfonic acid.[913a] A similar treatment of 3,5-dimethylisoxazole gave only the sulfonic acid. The free acids and a number of salts were prepared. 4-Methylthiazole has been converted into the 5-sulfonic acid by treatment with oleum.[913b] Treatment of benzoxazolone with chlorosulfonic acid at 60° gives 50–60% of the 5-sulfonyl chloride.[913c]

Sulfonation of 2-N-Phenyl-1,2-naphtho-1,2,3-triazole. In an extensive investigation of the similarities of the 2-N-phenylnaphthotriazole and phenanthrene systems of compounds it was found[914] that the former compound when heated with 20% of its weight of sulfuric acid at 180° produced the 4-sulfonic acid whereas with excess of the sulfonating agent a disulfonic acid was formed.[915]



Sulfonation of Alkaloids. The alkaloids containing an open position *para* to a methoxy or hydroxy group may be sulfonated by the use of sulfuric acid[916] below 10°. Papaverine[916, 917] yields a monosulfonic acid, reaction probably occurring in the 6′-position. Narcotine with sulfuric acid in acetic anhydride solution is also monosulfonated.[918]



Although no morphinesulfonic acid can be obtained by direct substitution a number of related compounds have been sulfonated.[919] Codeine N-oxide gives with sulfuric acid in acetic anhydride two isomeric sulfonic acids.[920] Tetrahydro-α-methylmorphimethine[921] and sinomenine[916] behave similarly. Although it is not closely related to morphine structurally it may be mentioned that apomorphine has also been sulfonated.[916]

The ease with which quinine and its derivatives are converted into "sulfonic acids," and the rapidity with which the acids hydrolyze has led to the belief that they are not true sulfonic acids but acid esters of the alcohol group present in the alkaloids.[922]

REFERENCES FOR A. SULFONATION REACTIONS

1. Lauer, *J. prakt. Chem.*, [2] **143**, 127 (1935).
2. Lantz, *Bull. soc. chim.*, **6**, 302 (1939); Spryskov, *J. Gen. Chem.* (*U.S.S.R.*), **8**, 1857 (1938); *C.A.*, **33**, 5820 (1939). Other references are cited in sections dealing with the sulfonation of individual compounds.
3. Simpson and Olsen, *Ind. Eng. Chem.*, **29**, 1350 (1937).
4. Tanasescu and Macarovici, *Bull. soc. chim.*, [5] **5**, 1126 (1938).

5*a*. Michael and Adair, *Ber.*, **10**, 585 (1877). *b*. Mitscherlich, *Pogg. Ann.*, **31**, 284 (1834). *c*. Freund, *Ann.*, **120**, 77 (1861). *d*. Stenhouse, *Ann.*, **140**, 285 (1866). *e*. Martinsen, *Z. physik. Chem.*, 59, 620 (1907).

6. Schotz, "Synthetic Organic Compounds," Ernest Benn, London, 1925, p. 185.
7. Zakharov, *J. Chem. Ind.* (*U.S.S.R.*), **6**, 1648 (1929); *C.A.*, 25, 5154 (1931).
8. Guyot, *Chimie et industrie*, **2**, 879 (1919).
9. Courtot, *Rev. gén. mat. color.*, **33**, 177 (1929).

10*a*. Courtot and Bonnet, *Compt. rend.*, **182**, 855 (1926). *b*. Vorozhtzov, *C.A.*, **28**, 4652 (1934).

11. Compagnie des Produits Chimiques de L'Alais et de la Camargue, British pat., 101,973, *C.A.*, **11**, 688 (1917); Tyrer, U. S. pat., 1,210,725, *C.A.*, **11**, 689 (1917); Ambler and Gibbs, U. S. pat., 1,300,228, *C.A.*, **13**, 1863 (1919); Barbet, U. S. pat., 1,459,081, *C.A.*, **17**, 2715 (1923); Killeffer, *Ind. Eng. Chem.*, **16**, 1066 (1924); Harvey and Stegman, *C.A.*, **16**, 842 (1924); Mohr-

mann, *Ann.*, **410**, 385 (1915); Piotrovskiĭ, Russian pat., 31,428, *C.A.*, **28**, 2732 (1934).

12. Gericke, *Ann.*, **100**, 207 (1856).
13. Kekulé, *Z. Chem.*, 195 (1867).
14. Meyer, *Ann.*, **433**, 327 (1923); Gay, Auméras, and Mion, *Chimie et industrie*, **19**, 387 (1928).
15. Downs, U. S. pats., 1,279,295 and 1,279,296, *C.A.*, **12**, 2572 (1918); Bender, U. S. pat., 1,301,360, *C.A.*, **13**, 1862 (1919).

16*a*. Aylsworth, U. S. pat., 1,260,852, *C.A.*, **12**, 1469 (1918). *b*. Mazoński and Sucharda, *Przemysl Chem.*, **18**, 478 (1934); *C.A.*, **29**, 6218 (1935). *c*. Thomas, Anzilotti, and Hennion, *Ind. Eng. Chem.*, 32, 408 (1940). *d*. Simons, Passino, and Archer, *J. Am. Chem. Soc.*, **63**, 608 (1941).

17. Ambler and Cotton, *Ind. Eng. Chem.*, **12**, 968 (1920); see also Häuser and Korovits'ka, *C.A.*, **33**, 159 (1939).
18. Wendt, German pat., 71,556, *Frdl.*, **3**, 19.
19. Neumann, *Ann.*, **241**, 84 (1887).
20. Otto, *J. prakt. Chem.*, [2] **1**, 183 (1869).
21. Mitscherlich, *Pogg. Ann.*, **29**, 231 (1833); **31**, 283, 628 (1834); Gattermann, *Ber.*, 24, 2121 (1891); Hochstetter, *J. Am. Chem. Soc.*, **20**, 549 (1898); Ullmann and Cohn, "Ullmann's Enzyklopadie der technischen Chemie," Second Edition, Vol. II, p. 279 (1928); Dennis, Canadian pat., 177,138, *C.A.*, **11**, 3278 (1917); Beltzer, *Ind. chim. min. met.*, 4, 372 (1917).

22*a*. Grob and Adams, U. S. pat., 1,422,564, *C.A.*, **16**, 3094 (1922). *b*. Carr and Dahlen, U. S. pat., 1,999,955, *C.A.*, 29, 4029 (1935). *c*. Suter, Evans, and Kiefer, *J. Am. Chem. Soc.*, **60**, 538 (1938). *d*. See also Planovskiĭ and Kagan, *Org. Chem. Ind.* (*U.S.S.R.*), 7, 296 (1940); *C.A.*, 35, 3986 (1941).

23*a*. Carr, U. S. pat., 2,000,061, *C.A.*, 29, 4027 (1935). *b*. Topchieu and Paushkin, *J. Applied Chem.* (*U.S.S.R.*), **12**, 64 (1939); *C.A.*, **33**, 6812 (1939).

24. Gebler, *J. Chem. Ind.* (*U.S.S.R.*), **2**, 984 (1926); *C.A.*, **21**, 1450 (1927).
25. Ullmann, *Ber.*, **42**, 2057 (1909); Pummerer, *Ber.*, **42**, 1802, 2274 (1909); *Org. Syntheses*, **10**, 6 (1930), John Wiley & Sons, New York.
26. Knapp, *Z. Chem.*, 41 (1869).

27*a*. Steinkopf and co-workers, *J. prakt. Chem.*, [2] **117**, 1 (1927). *b*. Meyer and Schramm, *Z. anorg. allgem. Chem.*, 206, 24 (1932).

28. Pictet and Karl, *Compt. rend.*, **145**, 239 (1907); *Bull. soc. chim.*, [4] **3**, 1117 (1908).
29. For earlier work see: Garrick, *Z. Chem.*, 550 (1869); Meyer and Michler, *Ber.*, **8**, 674 (1875); Egli, *Ber.*, **8**, 817 (1875); Heinzelmann, *Ann.*, **188**, 159 (1878); Barth and Senhofer, *Ber.*, **8**, 1477 (1875); Koerner and Monselise, *Gazz. chim. ital.*, 6, 133 (1876); Binschedler and Busch, *Mon. Sci.*, 1169 (1878).
30. Holleman and Polak, *Rec. trav. chim.*, 29, 416 (1910); see also Voluinkin, *J. Applied Chem.* (*U.S.S.R.*), 9, 885 (1936); *C.A.*, **30**, 7555 (1936).

31*a*. Kamens'kiĭ-Shmidt, *Mem. Inst. Chem. Tech. Acad. Sci. Ukrain S.S.R.*, **3**, 21 (1937); *C.A.*, **31**, 5777 (1937). *b*. Grillet, U. S. pat., 1,956,571, *C.A.*, **28**, 4071 (1934).

32. Behrend and Mertelsmann, *Ann.*, **378**, 352 (1911).
33. Mohrmann, *Ann.*, **410**, 373 (1915).
34. Lauer, *J. prakt. Chem.*, [2] **138**, 81 (1933).
35. Sensemann, *Ind. Eng. Chem.*, **13**, 1124 (1921).

36. Lamberts, German pat., 113,784, *Chem. Zentr.*, II, 883 (1900); see also ref. 24.
37. Pollak, Heimberg-Krauss, Katscher, and Lustig, *Monatsh.*, **55**, 358 (1930).
38. Senhofer, *Ann.*, **174**, 243 (1874).
39. Jackson and Wing, *Am. Chem. J.*, **9**, 329 (1887).
40. Suter and Harrington, *J. Am. Chem. Soc.*, **59**, 2575 (1937).
41. Jaworsky, *Z. Chem.*, 220 (1865).
42. Engelhardt and Latschinoff, *ibid.*, 617 (1869).
43. Wolkow, *ibid.*, 321 (1870).
44*a*. Fahlberg, *Am. Chem. J.*, **1**, 170 (1879); *Ber.*, **12**, 1048 (1879). *b*. Beckurts, *Ber.*, **10**, 943 (1877). *c*. Müller, *Ber.*, **12**, 1348 (1879). *d*. Otto, *Ber.*, **13**, 1292 (1880). *e*. Claësson and Wallin, *Ber.*, **12**, 1848 (1879). *f*. Wallin, *Ber.*, **19**, 2952 (1886). *g*. Fahlberg and List, *Ber.*, **21**, 243 (1888).
45. Klason, *Ber.*, **19**, 2887 (1886).
46. Holleman and Caland, *Ber.*, **44**, 2504 (1911).
47. Holdermann, *Ber.*, **39**, 1252 (1906).
48*a*. Remsen and Fahlberg, *Am. Chem. J.*, **1**, 426 (1879). *b*. Kholevo and EItingon, *J. Applied Chem. (U.S.S.R.)*, **9**, 1465 (1936); *C.A.*, **31**, 2176 (1937).
49*a*. See also Ambler and Gibbs, U. S. pat., 1,292,950, *C.A.*, **13**, 963 (1919); U. S. pat., 1,300,227, *C.A.*, **13**, 1863 (1919). *b*. Puls, *Chem.-Ztg.*, **25**, 263 (1901). *c*. Fichter, Suenderhauf, and Goldach, *Helv. Chim. Acta*, **14**, 249 (1931). *d*. Popa and Velculescu, *Bul. chim. soc. romane chim.*, **33**, 3 (1930); *C.A.*, **26**, 5405 (1932). *e*. Lauer and Oda, *J. prakt. Chem.*, [2] **143**, 139 (1935).
50. Beckurts and Otto, *Ber.*, **11**, 2061 (1878).
51. Houmann and Köchlin, *Ber.*, **15**, 1114 (1884); Noyes, *Am. Chem. J.*, 8, 176 (1886).
52. Harding, *J. Chem. Soc.*, **119**, 1261 (1921).
53. McKie, *ibid.*, **113**, 799 (1918).
54. Steinkopf and Buchheim, *Ber.*, **54B**, 2963 (1921).
55. Blomstrand, *Ber.*, **4**, 717 (1871); Blomstrand and Hakenson, *Ber.*, **5**, 1085 (1872); Senhofer, *Ann.*, **164**, 126 (1872); Gnehm and Forrer, *Ber.*, **10**, 542 (1877); Claësson and Berg, *Ber.*, **13**, 1170 (1880).
56. Klason, *Ber.*, **19**, 2888 (1886); **20**, 352 (1887); Wynne and Bruce, *J. Chem. Soc.*, **73**, 738 (1898).
57*a*. Fahlberg, *Am. Chem. J.*, **2**, 182 (1880). *b*. Mieg and Wieners, U. S. pat., 2,215,083, *C.A.*, **35**, 756 (1941).
58. Claësson, *Ber.*, **14**, 307 (1881).
59. Sempotowski, *Ber.*, **22**, 2663 (1889).
60. Cruschtschoff, *Ber.*, **7**, 1166 (1874).
61. Moody, *Chem. News*, **71**, 197 (1895).
62. Pollak, Fiedler, and Roth, *Monatsh.*, **39**, 182 (1918).
63. Steinkopf and Hübner, *J. prakt. Chem.*, **141**, 193 (1934).
64. Moody, *Chem. News*, 79, 81 (1899).
65. Fittig, Schaeffer, and König, *Ann.*, **149**, 330 (1869).
66. Spica, *Gazz. chim. ital.*, **8**, 408 (1878); *Ber.*, **12**, 2367 (1879).
67. Meyer and Baur, *Ann.*, **219**, 299 (1883).
68. Gerhardt and Cahours, *Ann.*, **38**, 92 (1841); Jacobsen, *Ann.*, **146**, 86 (1868); Paterno and Spica, *Gazz. chim. ital.*, 9, 434 (1879); *Ber.*, **12**, **2367** (1879)
69. Balbiano, *Gazz. chim. ital.*, **7**, **3**45 (1877); *Ber.*, **10**, 890 (1877).
70. Estreicher, *Ber.*, **33**, **441** (1900); Klages, *Ber.*, **39**, **2132** (1906).

71. Kelbe and Pfeiffer, *Ber.*, **19**, 1728 (1886); Sinkowski, *Ber.*, **23**, 2417 (1890); Baur, *Ber.*, **24**, 2835 (1891).

72. Tollens and Fittig, *Ann.*, **131**, 315 (1864); Dafert, *Monatsh.*, **4**, 616 (1883); Klages, *Ber.*, **36**, 3689 (1903).

73. Bygdén, *J. prakt. Chem.*, [2] **100**, 1 (1919).

74*a*. Brochet, *Compt. rend.*, **117**, 117 (1893). *b*. Brochet, *Bull. soc. chim.*, [3] **9**, 688 (1893). *c*. Klages and Sautter, *Ber.*, **37**, 654 (1904). *d*. Klages, *Ber.*, **37**, 2308 (1904). *e*. Schweinitz, *Ber.*, **19**, 642 (1886).

75*a*. Krafft, *Ber.*, **19**, 2983 (1886). *b*. Nishizawa, Kawasaki, and Hiraoka, *J. Soc. Chem. Ind. Japan*, **39**, Suppl. binding 360 (1936); *C.A.*, **31**, 565 (1937). *c*. Kursanoff, *Ann.*, **318**, 318 (1901). *d*. Gustavson, *Compt. rend.*, **146**, 640 (1908). *e*. Kamienski and Wierzchowski, *Roczniki Chem.*, **15**, 92 (1935); *C.A.*, **29**, 5096 (1935); see also Osterhoff, U. S. pat., 2,145,369, *C.A.*, **33**, 3397 (1939).

76*a*. I. G. Farbenind. A.-G., German pat., 647,988, *C.A.*, **31**, 8074 (1937). *b*. British pat., 453,778, *C.A.*, **31**, 1122 (1937). *c*. DeGroote, U. S. pat., 2,081,795, *C.A.*, **31**, 4992 (1937). *d*. Deutsche-Houghton Fabrik A.-G., French pat., 825,861, *C.A.*, **32**, 6779 (1938). *e*. Kyrides, U. S. pat., 2,161,173, *C.A.*, **33**, 7438 (1939). *f*. Stirton and Peterson, *Ind. Eng. Chem.*, **31**, 856 (1939). *g*. Sisley, *Rev. gén. mat. color*, **42**, 41, 84, 124 (1938). *h*. Cupples, "U. S. Dept. Agr. Bur. Entomol. Plant Quarantine E-426," 24 pp., April, 1938. *i*. Günther and Hetzer, U. S. pat., 1,737,792, *C.A.*, **24**, 864 (1930). *j*. Marx, Brodersen, and Quaedvlieg, U. S. pat., 2,014,502, *C.A.*, **29**, 7529 (1935). *k*. Desseigne, *Compt. rend.*, **200**, 466 (1935). *l*. Kyrides, U. S. pat., 2,218,472, *C.A.*, **35**, 1151 (1941); U. S. pat., 2,232,117, *C.A.*, **35**, 3364 (1941). *m*. Flett, U. S. pat., 2,223,364, *C.A.*, **35**, 1804 (1941); U. S. pat., 2,247,365, *C.A.*, **35**, 6264 (1941). *n*. Guenther, Hausmann, and Frank, U. S. pat., 2,220,099, *C.A.*, **35**, 1548 (1941); Brandt, U. S. pat., 2,244,512, *C.A.*, **35**, 5603 (1941).

77. Kipping, *J. Chem. Soc.*, **91**, 209, 717 (1907); Luff and Kipping, *ibid.*, **93**, 2090 (1908); Kipping and Davies, *ibid.*, **95**, 69 (1909); Marsden and Kipping, *ibid.*, **93**, 198 (1908); Bygdén, *J. prakt. Chem.*, [2] **96**, 86 (1917).

78*a*. Jacobsen, *Ber.*, **17**, 2374 (1884). *b*. Kizhner, *J. Gen. Chem.* (*U.S.S.R.*), **3**, 578 (1933); *C.A.*, **28**, 2693 (1934).

79. Moody, *Chem. News*, **67**, 34 (1893).

80. Nakatsuchi, *J. Soc. Chem. Ind. Japan*, **33**, Suppl. binding **65B** (1930); *C.A.*, **24**, 2733 (1930).

81. Pfannenstill, *J. prakt. Chem.*, [2] **46**, 155 (1892).

82. Crafts, *Ber.*, **34**, 1352 (1901); Orlov, *C.A.*, **22**, 1762 (1928).

83. Kizhner and Vendelshtein, *C.A.*, **20**, 2316 (1926).

84. Jacobsen, *Ber.*, **10**, 1015 (1877); *Ann.*, **184**, 188 (1876).

85. Moody, *Chem. News*, **58**, 21 (1888).

86. Pollak and Meissner, *Monatsh.*, **50**, 237 (1928).

87. Wischen, *Ber.*, **23**, 3113 (1890).

88. Pollak and Lustig, *Ann.*, **433**, 191 (1923); Holleman, *Anales soc. españ. fis. quim.*, **27**, 473 (1929); *C.A.*, **24**, 85 (1930).

89. Holleman and Choufoer, *C.A.*, **18**, 3183 (1924).

90. Patterson, McMillan, and Somerville, *J. Chem. Soc.*, **125**, 2488 (1924); Nakatsuchi, *C.A.*, **24**, 4768 (1930).

91*a*. Fittig and Glinzer, *Ann.*, **136**, 305 (1865). *b*. Jacobsen, *Ber.*, **10**, 1009 (1877); **11**, 22 (1878). *c*. Krafft and Wilke, *Ber.*, **33**, **3209** (1900). *d*. Karslake and Huston, *J. Am. Chem. Soc.*, **36**, 1245 (1914).

92. Pollak and Schadler, *Monatsh.*, **39**, 144 (1918); Holleman, Choufoer, and Alozery, *Rec. trav. chim.*, **48**, 1080 (1929).

93. Holmes, *Am. Chem. J.*, **13**, 372 (1891).

94. Voswinkel, *Ber.*, **21**, 3500 (1878).

95. Voswinkel, *Ber.*, **21**, 2829 (1878); Fournier, *Bull. soc. chim.*, [3] **7**, 651 (1892); Allen and Underwood, *ibid.*, [2] **40**, 100 (1883).

96. Fittig and König, *Ann.*, **144**, 286 (1868); Aschenbrandt, *Ann.*, **216**, 214 (1882); Remsen and Noyes, *Am. Chem. J.*, **4**, 200 (1883).

97. Körner, *Ann.*, **216**, 224 (1882); Remsen and Keiser, *Am. Chem. J.*, **5**, 162 (1883).

98. Uhlhorn, *Ber.*, **23**, 3142 (1890).

99*a*. Baur, *Ber.*, **27**, 1608 (1894). *b*. Heise, *Ber.*, **24**, 771 (1891).

100*a*. Spilker, *Ber.*, **26**, 1539 (1893); Moschner, *Ber.*, **34**, **1257** (1901). *b*. Bamberger and Kitschelt, *Ber.*, **23**, 1563 (1890); Schroeter and Schrauth, German pat., 299,603, *Chem. Zentr.*, IV, 618 (1919). *c*. Schroeter, Svanoe, Einbeck, Geller, and Riebensohm, *Ann.*, **426**, 83 (1922). *d*. Bogert, Davidson, and Apfelbaum, *J. Am. Chem. Soc.*, **56**, 959 (1934). *e*. Bogert and Fourman, *ibid.*, 55, 4676 (1933). *f*. Veselý and Štursa, *Collection Czechoslov. Chem. Communications*, **6**, 137 (1934); *C.A.*, **28**, 5815 (1934).

101. Claus and Pieszcek, *Ber.*, **19**, 3090 (1886).

102. Wroblewsky, *Ann.*, **192**, 199 (1878).

103. Bayrac, *Bull. soc. chim.*, [3] **13**, 890 (1895); *Ann. chim.*, [7] **10**, 28 (1897).

104. Defren, *Ber.*, **28**, 2649 (1895).

105. Claus and Stüsser, *Ber.*, **13**, 899 (1880).

106. Widman, *Ber.*, **24**, 444 (1891).

107. Sprinkmeyer, *Ber.*, **34**, 1952 (1901).

108. Kelbe, *Ann.*, 210, 30 (1881); Spica, *Ber.*, **14**, 652 (1881); *Gazz. chim. ital.*, **12**, 487, 546 (1882); Armstrong and Miller, *Ber.*, **16**, 2750 (1883).

109. Kelbe and Czarnomski, *Ann.*, **235**, 285 (1886); *Ber.*, **17**, 1747 (1884).

110. Delalande, *Ann.*, **38**, 342 (1841); Sieveking, *Ann.*, **106**, 258 (1858); Beilstein and Kupffer, *Ann.*, **170**, 287 (1873).

111. Jacobsen, *Ber.*, **11**, 1058 (1878).

112. Claus and Cratz, *Ber.*, **13**, 901 (1880); Claus, *Ber.*, **14**, 2140 (1881).

113. Schorger, *J. Ind. Eng. Chem.*, **10**, 259 (1918).

114. Kelbe and Koschnitzky, *Ber.*, **19**, 1733 (1886); Dinesmann, German pat., 125,097, *Chem. Zentr.*, II, 1030 (1901).

115. Phillips, *J. Am. Chem. Soc.*, **46**, 686 (1924).

116. LeFèvre, *J. Chem. Soc.*, 1501 (1934).

117. Kuan, *J. Chem. Soc. Japan*, **52**, 473 (1931).

118. Philipp, German pat., 466,360, *C.A.*, **23**, 2191 (1929); German pat., 504,998, *C.A.*, **25**, 525 (1931).

119. Kelbe and Baur, *Ber.*, **16**, 2560 (1883).

120. Baur, *Ber.*, **24**, 2834 (1891); *Ber.*, **27**, 1615 (1894).

121. Nölting, *Ber.*, **25**, 786 (1892).

122. Nölting, *Chimie et industrie*, **8**, 722 (1921).

123. Widman, *Ber.*, **23**, 3084 (1890); **24**, 458 (1891).

124. Becke, *Ber.*, **23**, 3192 (1890).

125. Klages and Keil, *Ber.*, **36**, 1641 (1903).

126. Bigot and Fittig, *Ann.*, **141**, 166 (1867).

127*a*. Lipinski, *Ber.*, **31**, 940 (1898). *b*. Krafft and Göttig, *Ber.*, **21**, 3183 (1888).

128. Fileti, *Gazz. chim. ital.*, **21**, I, 17 (1891); Heise, *Ber.*, **24**, 771 (1891).

129. Kurssanow, *Chem. Zentr.*, I, 1744 (1907).

130*a*. Jacobsen, *Ber.*, **15**, 1853 (1882). *b*. *Ber.*, **19**, 2517 (1876).

131. Auwers and Wieners, *Ber.*, **58B**, 2815 (1925).

132*a*. Ernst and Fittig, *Ann.*, **139**, 188 (1866). *b*. Jacobsen, *Ann.*, **184**, 189, 199 (1876). *c*. Kelbe and Pathe, *Ber.*, **19**, 1546 (1886). *d*. Ostwald, *Z. physik. Chem.*, **1**, 77 (1887). *e*. Crafts, *J. Am. Chem. Soc.*, **23**, 238 (1901); *Ber.*, **34**, 1352 (1901). *f*. Schultz, *Ber.*, **42**, 3603 (1909). *g*. Meyer and Schlegl, *Monatsh.*, **34**, 575 (1913). *h*. Smith and Cass, *J. Am. Chem. Soc.*, **54**, 1606 (1932).

133. Töhl and Eberhard, *Ber.*, **26**, 2943 (1893).

134. Hofmann, *J. Chem. Soc.*, **2**, 113 (1850); *Ann.*, **71**, 134 (1849); Fittig, *Ann.*, **141**, 141 (1867); Rose, *Ann.*, **164**, 55 (1872); Ravikovich, *J. Russ. Phys.-Chem. Soc.*, **62**, 177 (1930); *C.A.*, **24**, 5588 (1930).

135. Jacobsen, *Ann.*, **146**, 96 (1868).

136. Moschner, *Ber.*, **34**, 1259 (1901).

137*a*. Holleman, *C.A.*, **24**, 87 (1930); Holleman, Choufoer, and Alozery, *Rec. trav. chim.*, **48**, 1075 (1929). *b*. Backer, *Rec. trav. chim.*, **54**, 544 (1935).

138. Klages, *J. prakt. Chem.*, [2] **65**, 399 (1902).

139. Gustavson, *J. prakt. Chem.*, [2] **72**, 63 (1905).

140. Stahl, *Ber.*, **23**, 991 (1890).

141. Uhlhorn, *Ber.*, **23**, 2349 (1890).

142. Darzens and Rost, *Compt. rend.*, **152**, 609 (1911); Nölting, *Ber.*, **25**, 791 (1892); Baur, *Ber.*, **27**, 1607 (1894); Valentiner, German pat., 69,072, *Frdl.*, **3**, 881.

143. Klages, *Ber.*, **40**, 2370 (1907); Schorger, *J. Am. Chem. Soc.*, **39**, 2678 (1917).

144. Armstrong and Miller, *Ber.*, **16**, 2259 (1883).

145. Jacobsen, *Ber.*, **7**, 1433 (1874); *Ann.*, **195**, 284 (1879); Töhl and Geyger, *Ber.*, **25**, 1533 (1892).

146. Jacobsen, *Ber.*, **20**, 896 (1887); Smith, "Organic Reactions," Vol. 1, p. 370.

147. Smith and Lux, *J. Am. Chem. Soc.*, **51**, 2994 (1929).

148. Jacobsen, *Ber.*, **19**, 1214 (1886).

149. Bielefeldt, *Ann.*, **198**, 381 (1879); Jacobsen, *Ber.*, **15**, 1853 (1882).

150. Markownikoff and Ogloblin, *Ann.*, **234**, 101 (1886).

151. Jacobsen and Schnapauff, *Ber.*, **18**, 2841 (1885).

152*a*. Töhl and Tripke, *Ber.*, **28**, 2463 (1895). *b*. Smith and Kiess, *J. Am. Chem. Soc.*, **61**, 989 (1939).

153. Töhl and von Karchowski, *Ber.*, **25**, 1530 (1892).

154*a*. Klages and Stamm, *Ber.*, **37**, 1719 (1904). *b*. Jacobsen, *Ber.*, **21**, 2821 (1888). *c*. Smith and Guss, *J. Am. Chem. Soc.*, **62**, 2631 (1940).

155. Galle, *Ber.*, **16**, 1746 (1883).

156*a*. Schroeter, *Ber.*, **57**, 2009 (1924); Schroeter and Götzky, *Ber.*, **60B**, 2035 (1927); see also Godchot, *Bull. soc. chim.*, [4] **1**, 702 (1907); *Ann. chim. phys.*, [8] **12**, 486 (1907) for earlier observations. *b*. Schroeter, Müller, and Huang, *Ber.*, **62B**, 645 (1929).

157*a*. Holleman, *Rec. trav. chim.*, **24**, 30 (1905). *b*. Huntress and Carten, *J. Am. Chem. Soc.*, **62**, 511 (1940).

158. Glutz, *Ann.*, **143**, 184 (1867).
159. Otto and Brummer, *Ann.*, **143**, 102 (1867); Fischer, *Ber.*, **24**, 3188 (1891).
160. Baxter and Chattaway, *J. Chem. Soc.*, **107**, 1815 (1915).
161. Beckurts and Otto, *Ber.*, **11**, 2064 (1878).
162. Ullmann and Korselt, *Ber.*, **40**, 642 (1907).
163. Pummerer, *Ber.*, **42**, 1802 (1909).
164. Farbw. vorm. Meister, Lucius, and Brüning, German pat., 260,563, *C.A.*, **7**, 3198 (1913).
165. Olivier, *Rec. trav. chim.*, **38**, 351, 356 (1919).
166. Olivier, *ibid.*, **37**, 307 (1918).
167. Wibaut, van de Lande, and Wallagh, *ibid.*, **52**, 794 (1933).
168. Herzig, *Monatsh.*, **2**, 192 (1881).
169*a*. Couper, *Compt. rend.*, **45**, 231 (1857). *b.* Garrick, *Z. Chem.*, 549 (1869). *c.* Meyer and Nölting, *Ber.*, **7**, 1310 (1874). *d.* Nölting, *Ber.*, **8**, 595 (1875); Goslich, *Ber.*, **8**, 352 (1875); *Ann.*, **180**, 93 (1876).
170. Spiegelberg, *Ann.*, **197**, 257 (1879).
171. Armstrong, *J. Chem. Soc.*, **24**, 173 (1871); *Chem. News*, **23**, 188 (1871).
172. Fischer, *Ber.*, **24**, 3805 (1891).
173. Olivier and Kleermaeker, *Rec. trav. chim.*, **39**, 640 (1920).
174. Neumann, *Ann.*, **241**, 36 (1887).
175. Korner and Paterno, *Gazz. chim. ital.*, **2**, 448 (1872).
176. Langmuir, *Ber.*, **28**, 91 (1895); Troeger and Hurdelbrink, *J. prakt. Chem.*, [2] **65**, 82 (1902); Willgerodt and Waldeyer, *ibid.*, [2] **59**, 194 (1899).
177. Friedel and Crafts, *Ann. chim.*, [6] **10**, 413 (1887).
178. Beilstein and Kurbatow, *Ann.*, **176**, 41 (1875); **182**, 94 (1876).
179. Holleman and van der Linden, *Rec. trav. chim.*, 30, 332 (1911).
180. Lauer, *J. prakt. Chem.*, [2] **138**, 81 (1933).
181. Chem. Fabr. Griesheim-Elektron, German pat., 137,119, *Chem. Zentr.*, I, 112 (1903); Kybides, U. S. pat., 1,993,722, *C.A.*, **29**, 2546 (1935).
182. Davies and Poole, *J. Chem. Soc.*, 1122 (1927).
183. Pollak and Wienerberger, *Monatsh.*, **35**, 1472 (1914).
184. Lesimple, *Z. Chem.*, 226 (1868).
185. Crauw, *Rec. trav. chim.*, 50, 753 (1931).
186. Stewart, *J. Chem. Soc.*, **121**, 2555 (1922).
187. Gebauer-Fülnegg, and Figdor, *Monatsh.*, **48**, 627 (1927).
188. Woelz, *Ann.*, **168**, 81 (1873); Hübner and Williams, *Ann.*, **167**, 118 (1873); Borns, *Ann.*, **187**, 351 (1877).
189. Boyle, *J. Chem. Soc.*, **95**, 1683 (1909).
190. Armstrong and Briggs, *Chem. News*, **65**, 139 (1892).
191. Armstrong, *J. Chem. Soc.*, **97**, 1578 (1910).
192. Reinke, *Ann.*, **186**, 272 (1877).
193. Bössman, *Ann.*, **191**, 208 (1878); Kohlhase, *J. Am. Chem. Soc.*, **54**, 2445 (1932).
194. Rosenberg, *Ber.*, **19**, 654 (1886).
195. Cohen and Dutt, *J. Chem. Soc.*, **105**, 502 (1914).
196. Cohen and Smithells, *ibid.*, **105**, 1909 (1914).
197. Jacobsen, *Ber.*, **22**, 1580 (1889).
198. Rose, *Ann.*, **164**, 63 (1872); Töhl and Eckel, *Ber.*, **26**, 1102 (1893).
199. Töhl and Miller, *Ber.*, **26**, 1109 (1893).
200. Töhl, *Ber.*, **25**, 1528 (1892); Smith and Moyle, *J. Am. Chem. Soc.*, **58**, 1 (1936).

201*a*. JACOBSEN, *Ber.*, **20**, 2838 (1887). *b*. LAUER, *J. prakt. Chem.*, [2] **142**, 252 (1935). *c*. SMITH and MOYLE, *J. Am. Chem. Soc.*, **55**, 1676 (1933). *d*. I. G. FARBENIND. A.-G., British pat., 463,559, *C.A.*, **31**, 5817 (1937); ZITSCHER and KEHLEN, U. S. pat., 2,141,893, *C.A.*, **33**, 2730 (1939). *e*. SCHROETER, ERZBERGER, and PASSAVANT, *Ber.*, **71B**, 1040 (1938).

202. SCHMITT, *Ann.*, **120**, 164 (1861); ROSE, *Z. Chem.*, 234 (1871); MEYER and STUBER, *Ann.*, **165**, 164 (1873); LIMPRICHT, *Ann.*, **177**, 62 (1875); ELBS and WOHLFART, *J. prakt. Chem.*, [2] 66, 559 (1902); HOLLEMAN, *Rec. trav. chim.*, **24**, 198 (1905).

203. OBERMILLER, *J. prakt. Chem.*, [2] **89**, **84** (1914).

204. EKBOM, *Ber.*, **35**, 651 (1902).

205. See REESE, *Chem. Rev.*, **14**, 64 (1934), for a discussion.

206. CHEM. FABR. V. HEYDEN, German pat., 89,997, *Frdl.*, **4**, 39.

207. HARTMAN and ROLL, Eastman Kodak Company, private communication.

208. SCHMITT, *Ann.*, **120**, 164 (1861).

209. GRIFFITH, *J. Chem. Soc.*, **125**, 1401 (1924).

210. HESS, *Ber.*, **14**, 490 (1881).

211*a*. BEK, *Z. Chem.*, 209 (1869). *b*. BEILSTEIN and KUHLBERG, *Ann.*, **155**, 8 (1870). *c*. KORNATZKI, *Ann.*, **221**, 180 (1883).

212. VAN DORSSEN, *Rec. trav. chim.*, **29**, 379 (1910).

213. JAWORSKY, *Z. Chem.*, 22 (1865); ASCHER, *Ann.*, **161**, 1 (1871); *Ber.*, **4**, 649 (1871); JENSSEN, *Ann.*, **172**, 230 (1874); SCHWANERT, *Ann.*, **186**, 350 (1877); HART and REMSEN, *Ber.*, **10**, 1046 (1877); HART, *Am. Chem. J.*, **1**, 350 (1878); WALTER, *Chem. Industry* (German), **10**, 309 (1887).

214. MARTINSEN, *Z. physik. Chem.*, 62, 714 (1908).

215. ULLMANN and LEHNER, *Ber.*, **38**, 738 (1905).

216. BEILSTEIN and KUHLBERG, *Ann.*, **156**, 207 (1870); SCHULTZ and FLACHSLÄNDER, *J. prakt. Chem.*, [2] 66, 162 (1902).

217*a*. HARMSEN, *Ber.*, **13**, 1559 (1880). *b*. LIMPRICHT and VAN RIESEN, *Ber.*, **18**, 2191 (1885). *c*. CLAUS and SCHMIDT, *Ber.*, **19**, 1418 (1886).

218. FISCHER, *Ber.*, **24**, 3187 (1891).

219. AUGUSTIN and POST, *Ber.*, **8**, 1559 (1875).

220. CLAUS and MANN, *Ann.*, **265**, 88 (1891); ULLMANN and JÜNGEL, *Ber.*, **42**, 1077 (1909).

221. KATZ and JAMES, *J. Am. Chem. Soc.*, **35**, 872 (1913).

222. POST and MEYER, *Ber.*, **14**, 1605 (1881); CLAUS and BOPP, *Ann.*, **265**, 96 (1891).

223. BADISCHE ANILIN- UND SODAFABRIK, German pat., 162,635, *Chem. Zentr.*, II, 1142 (1905).

224. WALLACH and WÜSTEN, *Ber.*, **16**, 150 (1883).

225. ENGELHARDT, *Z. Chem.*, **44** (1864).

226. GEIGY AND CO., German pat., 91,315, *Frdl.*, **4**, 186.

227. GES. FÜR CHEM. INDUSTRIE, German pat., 98,229, *Chem. Zentr.*, II, 743 (1898).

228. GEIGY AND CO., German pat., 199,943, *ibid.*, II, 363 (1908).

229. SCHÖPFF, *Ber.*, **24**, 3783 (1891).

230. GILLIARD, MONNET, and CARTIER, German pat., 134,978, *Chem. Zentr.*, II, 1083 (1902).

231. BAYER AND CO., German pat., 105,006, *Frdl.*, **5**, 137.

232. BAYER AND CO., German pat., 228,838, *Chem. Zentr.*, I, 51 (1911).

233*a*. KREKELER, *Ber.*, **19**, 678, 2626 (1886). *b*. WESTON and SUTER, *J. Am. Chem. Soc.*, **61**, 390 (1939).

234. RIESZ and FRANKFURTER, *Monatsh.*, **50**, 68 (1928).

235. Bruhns, *Ber.*, **34**, 96 (1901).
236. Matthews, *J. Chem. Soc.*, **73**, 431 (1898).
237. Senderens, *Compt. rend.*, **198**, 1655, 1827 (1934).
238. Maarse, *Rec. trav. chim.*, **33**, 207 (1914).
239. See also *a*. Barth, *Ann.*, **148**, 33 (1868). *b*. Offermann, *Ann.*, **280**, 6 (1894). *c*. Taverne, *Rec. trav. chim.*, **25**, 55 (1905). *d*. Holdermann, *Ber.*, **39**, 1253 (1906). *e*. Senderens and Aboulenc, *Compt. rend.*, **186**, 1497 (1928).
240. Dimroth and Schmaedel, *Ber.*, **40**, 2411 (1907).
241. Reese, *J. Am. Chem. Soc.*, **54**, 2009 (1932); *Textile Research*, 4, 183 (1934).
242. Rây and Dey, *J. Chem. Soc.*, **117**, 1405 (1920).
243. Auger and Vary, *Compt. rend.*, **173**, 239 (1921); *Bull. soc. chim.*, [4] **29**, 990 (1921).
244. Mitscherlich, *Pogg. Ann.*, **32**, 227 (1834); *Ann.*, **12**, 314 (1843); Remsen, *Ann.*, **178**, 279 (1875).
245. Oppenheim, *Ber.*, **3**, 736 (1870).
246. Kämmerer and Carius, *Ann.*, **131**, 155 (1864); Kämmerer, *Ber.*, **4**, 219 (1871); Ador and Oppenheim, *Ber.*, **3**, 738 (1870).
247. Bergmann and Radt, *Ber.*, **54B**, 1652 (1921).
248*a*. Barth and Senhofer, *Ann.*, **159**, 217 (1871). *b*. Hohenemser, *Ber.*, **35**, 2305 (1902). *c*. Smiles and Stewart, *J. Chem. Soc.*, **119**, 1795 (1921).
249. Lock and Nottes, *Monatsh.*, **68**, **51** (1936); Suter and Weston, *J. Am. Chem. Soc.*, **61**, 531 (1939).
250. Engelhardt, *Ann.*, **108**, 343 (1858).
251. Schwanert, *Ann.*, **112**, 66 (1859).
252. Cöllen, *Ann.*, **191**, 29 (1878); Ullmann, *Am. Chem. J.*, **16**, 535 (1894).
253. Otto, *Ann.*, **123**, 216 (1862).
254. Roetters Van Lennep, *Z. Chem.*, 67 (1871); Hübner and Upmann, *ibid.*, 295 (1870).
255. Böttinger, *Ber.*, **7**, 1782 (1874).
256*a*. Fischer, *Ber.*, **24**, 3803 (1891). *b*. Van Dorssen, *Rec. trav. chim.*, **29**, 373 (1921).
257. Böttinger, *Ann.*, **191**, 14 (1878).
258. Jacobsen and Wierss, *Ber.*, **16**, 1958 (1883).
259. Baudisch and Perkin, *J. Chem. Soc.*, **95**, 1883 (1909).
260. Fischli, *Ber.*, **12**, 616 (1879); Weinreich, *Ber.*, **20**, 981 (1887); Meldrum and Perkin, *J. Chem. Soc.*, **93**, 1419 (1908).
261. Jacobsen, *Ber.*, **14**, 2357 (1881); Meldrum and Perkin, *J. Chem. Soc.*, **95**, 1891 (1909).
262. Remsen and Brown, *Am. Chem. J.*, **3**, 218 (1881).
263*a*. Widman, *Ber.*, **22**, 2278 (1889). *b*. Hausmann, German pat., 289,028, *Chem. Zentr.*, I, 194 (1916).
264. Goring, *Jahresbericht*, 859 (1877).
265. Rudnew, *J. Russ. Phys.-Chem. Soc.*, **5**, 412 (1873); *Ann.*, **173**, 10 (1874); Moore, *J. Am. Chem. Soc.*, **25**, 622 (1903); Moore and Thomas, *ibid*, **44**, 367 (1922); Duin, *Rec. trav. chim.*, **41**, 402 (1922).
266. Moore and Tucker, *J. Am. Chem. Soc.*, **49**, 259 (1927).
267. Kafka, *Ber.*, **24**, 796 (1891).
268. Palmer, *Am. Chem. J.*, **4**, 161 (1882).
269. Loew, *Ann.*, **143**, 257 (1867).
270. Rée, *Ann.*, **233**, 217 (1886).

271. Soc. pour. l'ind. chim. à Bâle, German pat., 572,962, *C.A.*, **27**, 4250 (1933); German pat., 578,724, *C.A.*, **28**, 783 (1934).
272. Waldmann and Schwenk, *Ann.*, **487**, 287 (1931).
273. Missenden, *Chem. News*, **125**, 328 (1922).
274. Mildner, German pat., 500,914, *C.A.*, **24**, 4792 (1930).
275. Heine, *Ber.*, **13**, 493 (1880).
276. Lönnies, *Ber.*, **13**, 704 (1880).
277. Ascher, *Ann.*, **161**, 2 (1872); Schoop, *Ber.*, **14**, 223 (1881).
278*a*. Kekulé, *Z. Chem.*, 199 (1867); *Ber.*, **2**, 330 (1869). *b*. Post, *Ber.*, 8, 1548 (1875); *Ann.*, **205**, 65 (1880). *c*. Paul, *Z. angew. Chem.*, 9, 590 (1896). *d*. Hazard-Flamand, German pat., 141,751, *Chem. Zentr.*, I, 1324 (1903). *e*. Schultz and Ichenhaeuser, *J. prakt. Chem.*, [2] **77**, 114 (1908).
279. Obermiller, *Ber.*, **40**, 3623 (1907); German pat., 202,168, *Chem. Zentr.*, II, 1220 (1908).
280. Glutz, *Ann.*, **147**, 52 (1868).
281. Zehenter and Fauser, *J. prakt. Chem.*, [2] **117**, 233 (1927).
282. Buhtz, German pat., 482,868, *C.A.*, **24**, 444 (1930); Rassow and Schultsky, *Nitrocellulose*, **2**, 189 (1931); *C.A.*, **26**, 1264 (1932).
283. Obermiller, *Ber.*, **41**, 696 (1908).
284. Chamot and Pratt, *J. Am. Chem. Soc.*, **31**, 925 (1909); **32**, 630 (1910).
285. Englehardt and Latschinow, *Z. Chem.*, 298 (1869).
286. Burkhardt, *J. Chem. Soc.*, 337 (1933).
287. Hofmann and Biesalski, *Ber.*, **45**, 1394 (1912).
288. Baumgarten, *Ber.*, **59B**, 1976 (1926); see also Beckett, Harris, Wylam, Thomas, and Scottish Dyes, Ltd., British pat., 294,507, *C.A.*, **23**, 1909 (1929).
289. Kekulé, *Z. Chem.*, 693 (1866); Griess, *Ann.*, **137**, 69 (1866); Obermiller, *Ber.*, **40**, 3641 (1907); **41**, 701 (1908).
290. Marqueyrol and Carré, *Bull. soc. chim.*, **27**, 199 (1920).
291. Engelhardt and Latschinow, *Z. Chem.*, 270 (1868).
292. Pollak, Gebauer-Fülnegg, and Riesz, *Monatsh.*, **46**, 383 (1926).
293. Pollak, Von Fiedler, and Roth, *Monatsh.*, 39, 193 (1918); Arche and Eisenmann, German pat., 51,321, *Frdl.*, **2**, 218.
294. Cahours, *Ann.*, **52**, 331 (1844); *Ann. chim.*, [3] **10**, 327 (1844); Kekulé, *Z. Chem.*, 201 (1867); Gnehm and Knecht, *J. prakt. Chem.*, [2] **74**, 103 (1906).
295. Shober, *Am. Chem. J.*, **15**, 388 (1893); **18**, 865 (1896).
296. Friese, German pat., 588,709, *C.A.*, **28**, 2019 (1934).
297. Annaheim, *Ann.*, **172**, 47 (1874).
298. Zervas, *Ann.*, **103**, 342 (1857).
299. Huntress and Carten, *J. Am. Chem. Soc.*, **62**, 603 (1940).
300*a*. Lagai, *Ber.*, **25**, 1837 (1892). *b*. Opl and Lippmann, *Compt. rend.*, **68**, 1322 (1869).
301. Gattermann, *Ber.*, **32**, 1154 (1899).
302. Shober and Bowers, *Am. Chem. J.*, **25**, 76 (1901).
303*a*. Lohmann, *Ber.*, **24**, 2640 (1891). *b*. Lübbert, U. S. pat., 2,007,869, *C.A.*, **29**, 5862 (1935). *c*. Rosenhauer, U. S. pat., 2,120,512, *C.A.*, **32**, 5964 (1938); Swiss pat., 199,782, *C.A.*, **33**, 3494 (1939). *d*. Hartley, *J. Chem. Soc.*, 1828 (1939).
304. Engelhardt and Latschinow, *Z. Chem.*, 76 (1868).

305. Campbell, *J. Chem. Soc.*, **121**, 847 (1922).

306. Campbell, *J. Ind. Eng. Chem.*, **14**, 732 (1922).

307. Claus and Jackson, *J. prakt. Chem.*, [2] **38**, 333 (1888).

308. Hantke, *Ber.*, **20**, 3210 (1887).

309. Engelhardt and Latschinow, *Z. Chem.*, 621 (1869).

310. Zehenter, *Monatsh.*, **33**, 345 (1912).

311. Reverdin and Roethlisberger, *Helv. Chim. Acta*, **3**, 486 (1920); Tassinari, *Gazz. chim. ital.*, **19**, 343 (1889).

312. Schoepfle, Van Natta, and Clarkson, *J. Am. Chem. Soc.*, **50**, 1173 (1928).

313. Pollak, Gebauer-Fülnegg, and Riesz, *Monatsh.*, **46**, 387 (1926).

314. Riesz, Berndt, and Hitschmann, *ibid.*, **50**, 328 (1928).

315*a*. Riesz and Pilpel, *ibid.*, **50**, 335 (1928). *b*. Steinkopf and Jaeger, *J. prakt. Chem.*, [2] **128**, 63 (1930).

316*a*. Claus and Krauss, *Ber.*, **20**, 3089 (1887). *b*. Claus and Dreher, *J. prakt. Chem.*, [2] **39**, 366 (1889).

317. Haworth and Lapworth, *J. Chem. Soc.*, **125**, 1299 (1924).

318. Pollak, Gebauer-Fülnegg, and Riesz, *Monatsh.*, 46, 383 (1926).

319*a*. Anschütz and Hodenius, *Ann.*, **415**, 74 (1918). *b*. Zincke and Kempf, *Ber.*, **44**, 417 (1911).

320. Raschig, *Z. angew. Chem.*, **25**, 1944 (1912).

321. Zehenter, *Monatsh.*, **37**, 595 (1916).

322. Katscher, Lehr, Harnisch, and Steinhardt, *ibid.*, **56**, 381 (1930).

323. Mikeska, U. S. pat., 2,162,269, *C.A.*, **33**, 7438 (1939); Flett, U. S. pats., 2,134,711 and 2,134,712, *C.A.*, **33**, 994 (1939); U S. pat., 2,133,287, *C.A.*, **33**, 1417 (1939); Zink, British pat., 504,417, *C.A.*, **33**, 7439 (1939); Rummelsburg, U. S. pat., 2,148,087, *C.A.*, **33**, 3927 (1939); Osterhof, U. S. pat., 2,145,369, *C.A.*, **33**, 3397 (1939); Flett, U. S. pats., 2,205,946–8 and 2,205,950, *C.A.*, **34**, 7488 (1940); Schwartz, U. S. pat., 2,205,949, *C.A.*, **34**, 7488 (1940); Robinson, U. S. pat., 2,205,951, *C.A.*, **34**, 7489 (1940); Weisberg and Slachman, U. S. pat., 2,237,066, *C.A.*, **35**, 4521 (1941); Watanabe, Ken, and Kawamura, U. S. pat., 2,251,536, *C.A.*, **35**, 7071 (1941); Flett, U. S. pat., 2,249,757, *C.A.*, **35**, 7071 (1941).

324*a*. Gebauer-Fülnegg and Schlesinger, *Ber.*, **61B**, 781 (1928); Gebauer-Fülnegg and Riesz, Austrian pat., 119,960, *C.A.*, **25**, 1262 (1931). *b*. Oranienburger, Chem. Fabrik A.-G., German pat., 666,626, *C.A.*, **33**, 2249 (1939); I. G. Farbenind. A.-G., French pat., 837,744, *C.A.*, **33**, 5868 (1939).

325. Haworth and Lapworth, *J. Chem. Soc.*, **123**, 2982 (1923).

326. Hirwe and Jambhekar, *J. Indian Chem. Soc.*, **10**, 47 (1933).

327*a*. Remsen, *Ann.*, **179**, 107 (1875). *b*. Hirsch, *Ber.*, **33**, 3238 (1900). *c*. Meldrum and Shah, *J. Chem. Soc.*, **123**, 1986 (1923).

328. Mendius, *Ann.*, **103**, 45 (1857).

329. Pisanello, *Gazz. chim. ital.*, **18**, 351 (1888).

330. Cohn, *J. prakt. Chem.*, [2] **61**, 545 (1900).

331. Bayer and Co., German pat., 264,786, *Chem. Zentr.*, II, 1350 (1913).

332. Barth, *Ann.*, **148**, 38 (1868); Senhofer, *Ann.*, **152**, 102 (1869).

333. Griess, *Z. Chem.*, 538 (1864).

334. Kretschy, *Ber.*, **11**, 858 (1878); Datta and Mitter, *J. Am. Chem. Soc.*, **41**, 2037 (1919).

335. Klepl, *J. prakt. Chem.*, [2] **28**, 196 (1883); Biehringer and Borsum, *Ber.*, **48**, 1316 (1915); Medoka and Dobrovol'skaya, *J. Gen. Chem.* (*U.S.S.R.*), **10**, 705 (1940); *C.A.*, **35**, 2486 (1941).

336. Kölle, *Ann.*, **164**, 150 (1872).

337. Zervas, *Ann.*, **103**, 339 (1857); Parks, *Am. Chem. J.*, **15**, 337 (1893).

338*a*. Nachbaur, *J. prakt. Chem.*, [1] **75**, 45 (1858). *b*. Conklin and Johnson, *J. Am. Chem. Soc.*, **54**, 2914 (1932). *c*. Bayer and Co., German pat., 264,786, *Chem. Zentr.*, II, 1350 (1913). *d*. Wohl, *Ber.*, **43**, 3488 (1910).

339. Cousin, *Compt. rend.*, **117**, 113 (1893); *Bull. soc. chim.*, [3] **11**, 103 (1894); *Ann. chim.*, [7] **13**, 511 (1898).

340. Gentsch, *Ber.*, **43**, 2018 (1910).

341. Quilico, *Gazz. chim. ital.*, **57**, 793 (1927).

342. Pollak and Gebauer-Fülnegg, *Monatsh.*, **47**, 109 (1926).

343. Tiemann and Koppe, *Ber.*, **14**, 2019 (1881); Barell, *Pharm. Ztg.*, No. 13, 111 (1899); Hohle, *J. prakt. Chem.*, [2] **65**, 96 (1902).

344. Herzig and Pollak, *Monatsh.*, **25**, 808 (1896); Hoffmann-La Roche and Co., German pats., 105,052, 109,789, 232,645; Frankel, "Arzneimittelsynthese," Sixth Edition, Julius Springer, Berlin, 1927, p. 584; Chem. Fabr. von Heyden, German pat., 188,506, *Chem. Zentr.*, II, 1467 (1907); Krauss and Crede, *J. Am. Chem. Soc.*, **39**, 1432 (1917).

345. Paul, *Ber.*, **39**, 2777 (1906).

346. Rising, *Ber.*, **39**, 3689 (1906).

347. Paul, *Ber.*, **39**, 4093 (1906).

348. Barell, *Pharm. Ztg.*, No. 13, 111 (1899).

349. Rupp and v. Brixen, *Arch. Pharm.*, **264**, 698 (1926); Berkenheim and Albitzkaya, *J. Gen. Chem.* (*U.S.S.R.*), **4**, 104 (1934); *C.A.*, **28**, 5434 (1934).

350. Hoffmann-La Roche and Co., German pats., 212,389 and 215,050, *Chem. Zentr.*, II, 569, 1604 (1909).

351. Gaspari, *Gazz. chim. ital.*, **26**, II, 232 (1896); *Atti accad. Lincei*, [5] **5**, I, 396 (1896).

352. Hoffmann-La Roche and Co., German pat., 132,607, *Chem. Zentr.*, II, 314 (1902).

353. Brown and Robinson, *J. Chem. Soc.*, **111**, 953 (1917).

354. Biechele, *Ann.*, **151**, 109 (1869); Tiemann and Koppe, *Ber.*, **14**, 2026 (1881).

355. Darzens and Dubois, *J. pharm. chim.*, [5] **26**, 57 (1892); *Bull. soc. chim.*, [3] **7**, 713 (1892).

356. Piccard and Humbert, *Ber.*, **9**, 1480 (1876); Tedeschi, *Ber.*, **12**, 1267 (1879); Merz and Zetter, *Ber.*, **12**, 2037 (1879); Fischer, *Monatsh.*, **2**, 331 (1881); Kauffmann and de Pay, *Ber.*, **37**, 725 (1904).

357. Pollak, Gebauer-Fülnegg, and Blumenstock, *Monatsh.*, **46**, 499 (1926).

358. Piccard and Humbert, *Ber.*, **10**, 182 (1877).

359. Hazura and Julius, *Monatsh.*, **4**, 610 (1883); Hazura and Julian, *ibid.*, **5**, 188 (1884).

360. Senhofer and Brunner, *Chem. Zentr.*, 566 (1879).

361*a*. Suter and Hansen, *J. Am. Chem. Soc.*, **55**, 2080 (1933). *b*. Pollak and Wienerberger, *Monatsh.*, **35**, 1482 (1914).

362. I. G. Farbenind. A.-G., British pat., 495,414, *C.A.*, **33**, 3030 (1939).

363. Hesse, *Ann.*, **117**, 324 (1861).

364. Seyda, *Ber.*, **16**, 688,693 (1883); Hesse, *Ann.*, **114**, 301 (1860).

365. Pinnow, *Z. Elektrochem.*, **21**, 380 (1915); **23**, 243 (1917).

366. Kauffmann, *Ber.*, **40**, 841 (1907); **41**, 4422 (1908); Hantzsch, *Ber.*, **40**, 3537 (1907); **41**, 1214 (1908).

367. Hesse, *Ann.*, **110**, 195 (1859).

368. Gebauer-Fülnegg, and Neumann, *Monatsh.*, **50**, 236 (1928).

369. Litvay, Riesz, and Landau, *Ber.*, **62B**, 1863 (1929); Pollak and Gebauer-Fülnegg, *Monatsh.*, **47**, 109 (1926).
370. Kariof, *Ber.*, **13**, 1673 (1880).
371. Seyewitz and Paris, *Bull. soc. chim.*, [4] **13**, 486 (1913).
372. Seyewitz and Paris, *ibid.*, [4] **15**, 121 (1914).
373. Senhofer and Sarley, *Monatsh.*, **2**, 454 (1881).
374. Schiff, *Ann.*, **178**, 187 (1875).
375. Delage, *Compt. rend.*, **131**, 450 (1900); **133**, 298 (1901); **136**, 760, 893, 1202 (1903).
376. Anschütz, *Ann.*, **415**, 87 (1918).
377. Delage, *Compt. rend.*, **132**, 421 (1901).
378. Pollak, Gebauer-Fülnegg, and Litvay, *Monatsh.*, 47, **537** (1927).
379. Hirschel, *ibid.*, **23**, 194 (1902).
380. Bayer and Co., German pat., 74,602, *Frdl.*, **3**, 859.
381. Schiff, *Ann.*, **178**, 191 (1875).
382*a*. Pollak, Gebauer-Fülnegg, and Weinmayr, *Monatsh.*, **47**, 537 (1927). *b*. Dorn, Warren, and Bullock, *J. Am. Chem. Soc.*, **61**, 146 (1939).
383. Neville and Winther, *Ber.*, **13**, 1941 (1880); Huber, *Helv. Chim. Acta*, **15**, 1372 (1932).
384. Claus and Immel, *Ann.*, **265**, 82 (1891); Armstrong and Berry, *Chem. News*, **82**, 46 (1900).
385. Pechmann, *Ann.*, **173**, 195 (1874).
386. Amiantov and Titkov, *C.A.*, **27**, 5315 (1933).
387. Bayer and Co., German pat., 296,941, *C.A.*, **13**, 322 (1919); German pat., 307,284.
388. British Dyestuffs Corporation, Ltd., British pat., 175,019, *C.A.*, **16**, 2150 (1922); Baddiley, Payman, and Wignall, U. S. pat., 1,441,655, *C.A.*, **17**, 1030 (1923); German pat., 392,460, *Frdl.*, **14**, 405.
389. Fierz, Schlittler, and Waldmann, *Helv. Chim. Acta*, **12**, 663 (1929).
390. Fischer, Kissling, and Kracker, German pat., 541,258, *C.A.*, **26**, 1942 (1932); *Frdl.*, **18**, 405.
391. Fischer, Kissling, and Kracker, German pat., 565,412, *C.A.*, **27**, 1004 (1933).
392. Neelmeier and Lambertz, German pat., 573,193, *C.A.*, **27**, 2966 (1933).
393. Murphy and Oesch, U. S. pat., 1,794,861, *C.A.*, **25**, 2153 (1931); Reissue 18,873, *C.A.*, **27**, 4241 (1933).
394. Bamberger and Kunz, *Ber.*, **30**, 2275 (1897).
395. Bamberger and Hindermann, *Ber.*, **30**, 655 (1897); Seyewitz and Bloch, *Bull. soc. chim.*, [4] **1**, 326 (1907).
396. Baumgarten, *Ber.*, **59B**, 1976 (1926).
397. Evans, Ph.D. thesis, Northwestern University, 1935.
398. Evans, *Chem. News*, **73**, 54 (1896).
399*a*. Schmitt, *Ann.*, **120**, 132 (1861). *b*. Gattermann-Wieland, "Laboratory Methods of Organic Chemistry," Macmillan, New York, 1934, p. 185.
400. Gerhardt, *Ann.*, **60**, 312 (1846).
401*a*. Buckton and Hofmann, *Ann.*, **100**, 163 (1856). *b*. Goslich, *Ann.*, **180**, 95 (1875).
402. Lamberts, *German* pat., 113,784, *Chem. Zentr.*, II, 883 (1900).
403. Bischoff, *Ber.*, **23**, 1912 (1890).
404. Wenghofer, *J. prakt. Chem.*, [2] 16, 454 (1877).
405. Limpricht, *Ber.*, **7**, 1349 (1874); *Ann.*, **177**, 80 (1875).

406. Pratesi, *Ber.*, **4**, 970 (1871); Kopp, *Ber.*, **4**, 978 (1871).

407*a*. Limpricht, *Ber.*, **9**, 551 (1876). *b*. Heinzelmann, *Ann.*, **188**, 170 (1877); **190**, 226 (1877).

408. Limpricht and Biel, *Ber.*, **18**, **2182** (1885).

409. Lustig and Katscher, *Monatsh.*, **48**, 87 (1927).

410. Zander, *Ann.*, **198**, 25 (1879); Schultz, *Ber.*, **39**, 3345 (1906); Olivier, *Rec. trav. chim.*, **39**, 499 (1920); Neelmeier and Van Hulle, U. S. pat., 1,889,371, *C.A.*, **27**, 1364 (1933).

411. Beckmann and Köster, *Ann.*, **274**, 16 (1893); Wulfing, German pat., 65,212, *Frdl.*, **3**, 44.

412. Junghahn and Neumann, *Ber.*, **33**, 1366 (1900).

413. Söll and Stutzer, *Ber.*, **42**, 4539 (1909).

414. Stewart, *J. Chem. Soc.*, **121**, **2558** (1922); Gilman, *Org. Syntheses Coll.*, Vol. I, John Wiley & Sons, New York, 1932, p. 8; Miller, Rock, and Moore, *J. Am. Chem. Soc.*, **61**, 1198 (1939).

415. Ulrich and Körding, German pat., 599,692, *C.A.*, **28**, 7574 (1934); Blum, *Bull. soc. ind. Mulhouse*, **105**, 113, 116 (1939); Flett, U. S. pat., 2,166,949, *C.A.*, **33**, 8859 (1939).

416*a*. Engelhardt and Latschinow, *Z. Chem.*, 266 (1868). *b*. Hentzschel, *Ber.*, **18**, 979 (1885); *J. prakt. Chem.*, [2] **34**, 423 (1886). *c*. Cox, *J. Am. Chem. Soc.*, **62**, **743** (1940).

417. Schroeter and Eisleb, *Ann.*, **367**, 158 (1909).

418. Battegay and Schneider, *Bull. soc. chim.*, **41**, 1491 (**1927**).

419. Hentzschel, *Ber.*, **17**, 1288 (1884).

420. Reissert, *Ber.*, **37**, 3723 (1904).

421. Conrad and Zart, *Ann.*, **340**, **347** (1905).

422. Gilpin, *Am. Chem. J.*, **19**, 361 (1897).

423*a*. Gnehm and Scheutz, *J. prakt. Chem.*, [2] **63**, 410 (1901). *b*. Rassow, Döhle, and Reim, *ibid.*, [2] **93**, 191 (1916). *c*. Halberkann, *Ber.*, **54**, 1836 (1921). *d*. Uppal and Venkataraman, *J. Soc. Chem. Ind.*, **67**, 410 (1938).

424. Badische Anilin- und Sodafabrik, German pat., 48,151, *Frdl.*, **2**, 13.

425. Smyth, *Ber.*, **7**, 1241 (1874).

426. Bayer and Co., German pat., 295,104, *Chem. Zentr.*, II, 1097 (1916); Shirolkar, Uppal, and Venkataraman, *J. Indian Chem. Soc.*, **17**, 443 (1940).

427. Claasz, *Ann.*, **380**, 312 (1911).

428. Limpricht and Mundelius, *Ber.*, **7**, 1350 (1874); Ebersbach, *Z. physik. Chem.*, **11**, 609 (1893).

429. Smyth, *Ber.*, **6**, 344 (1873); **7**, 1237 (1874); Armstrong, *Ber.*, **6**, 663 (1873); Laar, *J. prakt. Chem.*, [2] **20**, 260 (1879); Michaelis and Godchaux, *Ber.*, **23**, 556 (1890); Ges. für chem. Ind., German pat., 44,792, *Frdl.*, **2**, 11.

430*a*. Jones and Millington, *Proc. Cambridge Phil. Soc.*, **12**, 489 (1904). *b*. Schirm, U. S. pat., 2,067,463, *C.A.*, **31**, 1524 (1937).

431. Borsche, *Ann.*, **377**, 86 (1910).

432. Gerver, *Ann.*, **169**, 374 (1873); Schultz and Lucas, *J. Am. Chem., Soc.*, **49**, 300 (1927).

433. Rây and Dey, *J. Chem. Soc.*, **117**, 1405 (1920); Davies, *ibid.*, **121**, 787 (1922).

434. Wynne and Bruce, *J. Chem. Soc.*, **73**, 738 (1898).

435. Neville and Winther, *Ber.*, **15**, **2992** (1882); Hasse, *Ann.*, **230**, 287 (1885).

436. Lorenz, *Ann.*, **172**, 185 (1874); Ostwald, *Z. physik. Chem.*, **3**, 412 (1889); Limpricht, *Ber.*, **7**, 448 (1874).

437. Shah, Bhatt, and Kanga, *J. Chem. Soc.*, 2010 (1934).
438. Sell, *Ann.*, **126**, 155 (1863); Janovsky and Reimann, *Ber.*, **21**, 1216 (1888).
439. Richter, *Ann.*, **230**, 314 (1885).
440*a*. Buff, *Ber.*, **3**, 796 (1870). *b*. Schneider, *Am. Chem. J.*, **8**, 274 (1886).
441*a*. Coffey, Haddock, and Imperial Chem. Industries, Ltd., British pat., 469,108, *C.A.*, **32**, 596 (1938). *b*. J. R. Geigy A.-G., Swiss pat., 210,340, *C.A.*, **35**, 5603 (1941).
442. Keller and Schulze, *Arch. Pharm.*, **263**, 481 (1925).
443. Griess, *J. prakt. Chem.*, [2] **5**, 244 (1872).
444. Chancel, *Compt. rend.*, **28**, 423 (1849).
445. Cunze and Hübner, *Ann.*, **135**, 113 (1865).
446. Plöchl and Loë, *Ber.*, **18**, 1182 (1885).
447. Erlenmeyer and Lipp, *Ann.*, **219**, 209 (1883).
448. Post and Hardtung, *Ann.*, **205**, 107 (1880).
449. Bayer and Co., German pat., 298,340, *Chem. Zentr.*, II, 257 (1917).
450. Wiesinger, *Ber.*, **7**, 464 (1874); Bückel, *Chem. Zentr.*, I, 1410 (1904).
451. A.-G. für Anilinfabrik, German pat., 146,655, *ibid.*, II, 1301 (1903); German pat., 198,469, *ibid.*, I, 2120 (1908).
452. Cohn, *Ann.*, **309**, 236 (1899).
453. Child, *J. Chem. Soc.*, 715 (1932).
454. Noyes and Clement, *Ber.*, **26**, 990 (1893); Noyes and Torrance, *Ber.*, **28**, 2351 (1895); Gattermann, *Ber.*, **27**, 1938 (1894).
455. Brunner and Kraemer, *Ber.*, **17**, 1867 (1884); Brunner and Vuilleumer, *C.A.*, **2**, 3346 (1908); Eckert, *Monatsh.*, **34**, 1959 (1913).
456. Bamberger, *Ber.*, **33**, 3602 (1900).
457*a*. Crossley and Ogilvie, *J. Am. Chem. Soc.*, **39**, 120 (1917). *b*. Sherk, Houpt, and Browne, *ibid.*, **62**, 329 (1940).
458. Post, *Ann.*, **205**, 49 (1880); Schmitt and Bennewitz, *J. prakt. Chem.*, [2] **8**, 8 (1873).
459. Bauer, *Ber.*, **42**, 2110 (1909).
460*a*. Hoffmann-La Roche and Co., German pat., 98,839, *Chem. Zentr.*, II, 1189 (1898). *b*. Imperial Chemical Ind., German pat., 667,794, *C.A.*, **33**, 3035 (1939).
461. Oehler, German pat., 70,788, *Frdl.*, **3**, 59.
462. Bayer and Co., German pat., 84,143, *Frdl.*, **4**, 113.
463. Agfa, German pat., 291,963, *Chem. Zentr.*, I, 1286 (1916); *Frdl.*, **13**, 479.
464. Hentrich and Hardtmann, German pat., 518,928, *C.A.*, **25**, 3361 (1931).
465. A.-G. für Anilinfabrik, German pat., 144,618, *Chem. Zentr.*, II, 974 (1903).
466. Bamberger and Rising, *Ann.*, **316**, 304 (1901).
467. Städler, *Ann.*, **116**, 91 (1850); Conklin and Johnson, *J. Am. Chem. Soc.*, **54**, 2914 (1932).
468. Ruge, *J. prakt. Chem.*, 96, 112 (1865).
469*a*. Jacob, *J. pharm. chim.*, [6] **12**, 210 (1900); *Chem. Zentr.*, II, 878 (1900). *b*. Lepetit and Levi, *Gazz. chim. ital.*, **41**, I, 677, 685 (1911).
470. Feldmann, *Helv. Chim. Acta*, **14**, 751 (1931).
471. Tschunkur and Kracht, German pat., 535,075, *C.A.*, **26**, 998 (1932); German pat., 535,855, *C.A.*, **26**, 998 (1932).
472. Grant and James, *J. Am. Chem. Soc.*, **39**, 936 (1917).
473*a*. Latschinow, *J. Russ. Phys.-Chem. Soc.*, **5**, 50 (1873); *Ber.*, **6**, 194 (1873). *b*. Latschinow and Engelhardt, *Z. Chem.*, 260 (1871).

474. McCullough, U. S. pat., 1,865,776, *C.A.*, **26**, 4347 (1932); see also Stoesser and Marschner, U. S. pat., 1,981,337, *C.A.*, **29**, 478 (1935).

475. Gebauer-Fülnegg, Riesz, and Ilse, *Monatsh.*, **49**, 41 (1928).

476. Pollak, Heimberg-Krause, Katscher, and Lustig, *ibid.*, **55**, 358 (1930).

477*a*. Fittig, *Ann.*, **132**, 209 (1864). *b*. I. G. Farbenind. A.-G., French pat., 837,855, *C.A.*, **33**, 6349 (1939).

478. Kruber, *Ber.*, **65B**, 1382 (1932).

479. Knauf and Adams, *J. Am. Chem. Soc.*, **55**, 4704 (1933).

480*a*. Klages, *Ber.*, **40**, 2371 (1907). *b*. Schroeter, Müller, and Huang, *Ber.*, **62B**, 645 (1929).

481. Courtot and Lin, *Bull. soc. chim.*, [4] **49**, 1047 (1931).

482. Gabriel and Dambergis, *Ber.*, **13**, 1408 (1880).

483*a*. Vorozhtzov and Troshchenko, Russian pat., 50,857, *C.A.*, **33**, 3818 (1939); *J. Gen. Chem.* (*U.S.S.R.*), **9**, 59 (1939). *b*. Diels and Bibergeil, *Ber.*, **35**, 312 (1902). *c*. Magoun, U. S. pat., 2,135,978, *C.A.*, **33**, 1416 (1939). *d*. Flett, U. S. pat., 2,223,363, *C.A.*, **35**, 1902 (1941).

484. Barth and Schreder, *Ber.*, **11**, 1335 (1878).

485. Moir, *J. Chem. Soc.*, **91**, 1306 (1907); Doebner, *Ber.*, **9**, 130 (1876).

486. Moir, *Proc. Chem. Soc.*, **22**, 259 (1906).

487. Selch, *Monatsh.*, **14**, 5 (1893).

488. Scholl, Liese, Michelson, and Grunewald, *Ber.*, **43**, 516 (1910).

489*a*. Carnelley and Schleselman, *J. Chem. Soc.*, **49**, 380 (1886). *b*. Van Meter, Bianculli, and Lowy, *J. Am. Chem. Soc.*, **62**, 3146 (1940); Halverstadt and Kumler, *ibid.*, **63**, 624 (1941).

490. Griess and Duisberg, *Ber.*, **22**, 2462 (1889).

491. Bayer and Co., German pat., 38,664, *Frdl.*, **1**, 500; German pat., 44,779, *Frdl.*, **2**, 495; Zehra, *Ber.*, **23**, 3459 (1890); Schultz and Kohlhaus, *Ber.*, **39**, 3341 (1906).

492. Griess, *Ber.*, **14**, 300 (1881).

493. Bayer and Co., German pat., 27,954, *Frdl.*, **1**, 495.

494. Courtot and Evain, *Bull. soc. chim.*, [4] **49**, 527 (1931).

495. A.-G. für Anilinfabrik, German pat., 172,106, *Chem. Zentr.*, II, 479 (1906); German pat., 174,497, *ibid.*, II, 1224 (1906).

496. Willstätter and Kalb, *Ber.*, **37**, 3770 (1904).

497. Limpricht, *Ber.*, **14**, 1543 (1881); **23**, 1053 (1890); *Ann.*, **261**, 310 (1891); Schultz, *Ann.*, **207**, 314 (1881).

498. Schenk, *Pharm. Ztg.*, **54**, 592 (1909); *C.A.*, **5**, 882 (1911); Wedekind and Schenk, *Ber.*, **44**, 201 (1911).

499*a*. Doer, *Ber.*, **5**, 796 (1872). *b*. Lapworth, *J. Chem. Soc.*, **73**, 408 (1898).

500. Mazzara, *Gazz. chim. ital.*, **8**, 509 (1878).

501. Zincke, *Ber.*, **5**, 685 (1872).

502. Rennie, *J. Chem. Soc.*, **41**, 34, 220, 226 (1882).

503. Paterno and Fileti, *Gazz. chim. ital.*, **3**, 126 (1873); *Ber.*, **6**, 757 (1873).

504. Rennie, *J. Chem. Soc.*, **49**, 406 (1886).

505. Kliegl, *C.A.*, **6**, 3270 (1912).

506. Eberhardt and Welter, *Ber.*, **27**, 1813 (1894).

507*a*. Geigy and Co., German pat., 65,017, *Frdl.*, **3**, 116; German pat., 88,085, *Frdl.*, **4**, 219. *b*. Haller and Guyot, *Bull. soc. chim.*, [3] **25**, 209 (1901); *Soc. St. Denis*, German pat., 112,913, *Chem. Zentr.*, II, 655 (1900).

508. Beckmann, *Ber.*, **6**, 1112 (1873); Städel, *Z. Chem.*, 553 (1871); *Ann.*, **194**, 314 (1878).

509. Höchster Farbwerke, German pat., 285,700, *Chem. Zentr.*, II, 448 (1915).
510. Claus, *Ber.*, **19**, 2881 (1886); Elbs, *J. prakt. Chem.*, [2] **35**, 478 (1887).
511. Elbs, *J. prakt. Chem.*, [2] **35**, 501 (1887).
512. Elbs, *ibid.*, [2] **41**, 146 (1890).
513. Limpricht and Lenz, *Ann.*, **286**, 309 (1895).
514. Limpricht and Falkenberg, *Ann.*, **286**, 335 (1895).
515. Kade, *Ber.*, **6**, 953 (1873).
516. Hepp, *Ber.*, **7**, 1421 (1874).
517. Limpricht and Schwanert, *Ann.*, **145**, 335 (1868).
518. Pfeiffer, *Ann.*, **411**, 140 (1916).
519. Elbs, *J. prakt. Chem.*, [2] **47**, 49 (1893).
520*a*. J. R. Geigy, A.-G., British pat., 506,610, *C.A.*, **33**, 9493 (1939); Swiss pats., 198,705, 200,241, and 200,242, *C.A.*, **33**, 3494 (1939). *b*. Pfeiffer and Negreanu, *Ber.*, **50**, 1465 (1917).
521. Liebermann and Bergami, *Ber.*, **22**, 128 (1889); Lange, *Ber.*, **27**, 1413 (1894).
522*a*. Perkin and Robinson, *J. Chem. Soc.*, **91**, 1088 (1907). *b*. Fittig, *Ann.*, **206**, 52 (1881). *c*. Oudemans, *Ann.*, **170**, 232 (1873).
523. Prahl, U. S. pat., 2,081,876, *C.A.*, **31**, 4993 (1937).
524*a*. Merz and Weith, *Ber.*, **5**, 283 (1872); *Ber.*, **6**, 1512 (1873). *b*. Dziewoński and Russocki, *C.A.*, **25**, 1503 (1931).
525. Wieland, *Ber.*, **52**, 890 (1919).
526. Cloez, *Compt. rend.*, **124**, 900 (1897).
527. Gnehm and Werdenburg, *Z. angew. Chem.*, **12**, 1027, 1051 (1899).
528. A.-G. für Anilinfabrik, German pat., 76,415, *Frdl.*, **4**, 87.
529. Wieland and Gambarjan, *Ber.*, **39**, 1504 (1906).
530. Cobenzl, *Chem.-Ztg.*, **39**, 859 (1915).
531*a*. Gnehm and Schönholzer, *J. prakt. Chem.*, [2] **76**, 502 (1907). *b*. Bayer and Co., German pat., 69,777, *Frdl.*, **3**, 39.
532. German pat., 68,291, *Frdl.*, **3**, 130.
533. Michaelis and Godchaux, *Ber.*, **23**, 558 (1890).
534. Höchster Farbwerke, German pat., 270,942, *Frdl.*, **11**, 381.
535. Beilstein, Fourth Edition, Suppl. Vol. XIV, p. 729.
536. Limpricht, *Ann.*, **144**, 317 (1867).
537. Schwalbe, *Z. Farben. Text. Chem.*, **1**, 653 (1902); *Chem. Zentr.*, I, 231 (1903).
538. Chrzaszczewska and Dobrowolski, *Roczniki Chem.*, **17**, 411 (1937); *C.A.*, **32**, 1674 (1938).
539*a*. Kekulé and Franchimont, *Ber.*, **5**, 908 (1872). *b*. v. Liebig, *Ann.*, **360**, 242 (1908).
540. Erdmann and Erdmann, *Ann.*, **294**, 386 (1897).
541. Friedlander, *Frdl.*, **1**, 106.
542. Höchster Farbwerke, German pat., 175,825, *Chem. Zentr.*, II, 1749 (1906).
543. Giacalone and Scarpinati, *Gazz. chim. ital.*, **62**, 189 (1932); *C.A.*, **26**, 4324 (1932).
544. Schmidlin, *Ber.*, **39**, 4204 (1906).
545. Herz, *Ber.*, **23**, 2541 (1890).
546. Japp and Wadsworth, *J. Chem. Soc.*, **57**, 965 (1890).
547. Thiele and Ruggli, *Ann.*, **393**, 80 (1912).
548. Engler, *Ber.*, **11**, 929 (1878).
549. Behr, *Ber.*, **5**, 278 (1872).

550. Elbs, *Ber.*, **17**, 704 (1884).

551. Brande, *Quart. J. Science*, 8, **289** (1819).

552*a*. Faraday, *Phil. Trans. Roy. Soc.*, **116**, II, 140 (1826); *Ann., chim. phys.*, [2] **34**, 164 (1827); *Pogg. Ann.*, **7**, 104 (1826); see also *b*. Kidd, *Phil. Trans. Roy. Soc.*, **111**, 216 (1821). *c*. Chamberlain, *Annals of Phil.*, 6, 136 (1823). *d*. Liebig and Wöhler, *Pogg. Ann.*, **24**, 169 (1832). *e*. Berzelius, *ibid.*, **44**, 377 (1838); *Ann. chim. phys.*, [2] **65**, 290 (1837). *f*. Regnault, *Ann.*, **22**, 70 (1837); *Ann. chim. phys.*, [2] 65, 87 (1837). *g*. Hodgson, *Z. Farben-Ind.*, **20**, 124 (1928) reviews sulfonation reactions of naphthalene and derivatives.

553*a*. Merz, *Z. Chem.*, 395 (1868). *b*. Merz and Weith, *Ber.*, **3**, 195 (1870). *c*. Merz and Mühlhäuser, *Ber.*, **3**, 710 (1870).

554*a*. Armstrong and Wynne, *Ber.*, **24R**, 718 (1891). *b*. Ufimtzev, *J. Gen. Chem. (U.S.S.R.)*, **6**, 653 (1935); *C.A.*, **29**, 7316 (1935).

555. Euwes, *Rec. trav. chim.*, **28**, 298 (1909).

556. Fierz and Weissenbach, *Helv. Chim. Acta*, **3**, 316 (1920).

557. Fierz-David, *J. Soc. Chem. Ind.*, **42**, 421T (1923).

558*a*. Ioffe, *Anilinokrasochnaya Prom.*, **3**, 296 (1933); *C.A.*, **28**, 957 (1934); *J. Gen. Chem. (U.S.S.R.)*, **3**, 437, 505 (1933); *C.A.*, **28**, 1593 (1934). *b*. See, however, Lantz, *Compt. rend.*, **201**, 149 (1935). *c*. Fedorov and Spruiskov, *Org. Chem. Ind. (U.S.S.R.)*, 2, 100 (1936); *C.A.*, **31**, 678 (1937).

559. Fierz and Weissenbach, *Helv. Chim. Acta*, **3**, 312 (1920).

560. Witt, *Ber.*, **48**, 743 (1915).

561. Dennis, U. S. pat., 1,332,203, *C.A.*, **14**, 1123 (1920).

562. Southcombe and Downie, British pat., 120,405, *C.A.*, **13**, 610 (1919).

563. Grishin and Spruiskov, *C.A.*, **27**, 4791 (1933).

564*a*. Spruiskov, *C.A.*, **26**, 2735 (1932). *b*. Hill, U. S. pat., 1,848,883, *C.A.*, **26**, 2747 (1932).

565. Landshoff and Meyer, German pat., 50,411, *Frdl.*, **2**, 241.

566. Armstrong, *J. Chem. Soc.*, **24**, 176 (1871); *Ber.*, **4**, 357 (1871).

567. Radcliffe and Short, *J. Chem. Soc.*, 220 (1931).

568. Baumgarten, German pat., 514,821, *C.A.*, **25**, 2156 (1931).

569. J. R. Geigy Soc. anon., French pat., 765,771, *C.A.*, **28**, 6726 (1934).

570*a*. Masters, U. S. pat., 1,922,813, *C.A.*, **27**, 5085 (1933). *b*. Vorozhtzov and Krasova, *C.A.*, **27**, 5321 (1933).

571. Chuksanova and Bilik, *C.A.*, **28**, 3729 (1934).

572*a*. Fierz-David and Hasler, *Helv. Chim. Acta*, **6**, 1133 (1923). *b*. A.-G. für Anilinfabrik, German pat., 45,776, *Frdl.*, **2**, 253. *c*. Bernthsen, *Ber.*, **22**, 3327 (1889). *d*. Schultz, *Ber.*, **23**, 77 (1890). *e*. Armstrong and Wynne, *Chem. News*, 55, 136 (1887).

573. Baum, German pat., 61,730, *Frdl.*, **3**, 419.

574. Ufimzew and Kriwoschlükowa, *J. prakt. Chem.*, [2] **140**, 172 (1934); Chuksanova, *C.A.*, **34**, 5834 (1940).

575. Ewer and Pick, German pat., **45**,229, *Frdl.*, **2**, 244; Chuksanova and Bilik, *C.A.*, **29**, 1085 (1935).

576*a*. Ebert and Merz, *Ber.*, 9, 592 (1876). *b*. Armstrong, *Ber.*, **15**, **204** (1882). *c*. Willard, *Color Trade J.*, **15**, 40 (1924).

577. Heid, *J. Am. Chem. Soc.*, **49**, **844** (1927).

578. Landshoff and Meyer, German pat., 48,053, *Frdl.*, **2**, **243**.

579. Haller and Lynch, *Ind. Eng. Chem.*, **16**, 273 (1924).

580*a*. Ambler, Lynch, and Haller, *ibid.*, **16**, 1264 (1924). *b*. I. G. Farbenind. A.-G., French pat., 837,855, *C.A.*, **33**, 6349 (1939).

581*a*. Corbellini, *Giorn. chim. ind. appl.*, 9, 118 (1927); *C.A.*, **22**, 2938 (1928). *b*. Armstrong, *Ber.*, **15**, 205 (1882); *Chem. News*, **54**, 255 (1886). *c*. Bernthsen and Semper, *Ber.*, **20**, 938 (1887).

582. Armstrong and Wynne, *Proc. Chem. Soc.*, **3**, 146 (1887); *Chem. News*, **57**, 9 (1888).

583. Erdmann, *Ber.*, **32**, 3188 (1899).

584. Gurke and Rudolph, German pat., 38,281, *Frdl.*, **1**, 385; Busse, Bregman, and Trokhimovskaya, *C.A.*, **28**, 5432 (1934); Ufimtsev, Russian pat., 50,-689, *C.A.*, **32**, 2147 (1938); Ufimtsev and Krivoshlykova, *C.A.*, **31**, 1021 (1937).

585. Cassella and Co., German pat., 75,432, *Frdl.*, **3**, 420.

586. Schmid, "Diss. Eidgen. Tech. Hochschule," Zürich, 1920; *C.A.*, **16**, 2141 (1922); Fierz and Schmidt, *Helv. Chim. Acta*, **4**, 381 (1921); Bayer and Co., German pat., 80,464, *Frdl.*, **4**, 605.

587. Bayer and Co., German pat., 79,054, *Frdl.*, **4**, 589; Senhofer, *Ber.*, **8**, 1486 (1875); *Monatsh.*, **3**, 112 (1882).

588. Fittig and Remsen, *Ann.*, **155**, 115 (1870).

589. Reingruber, *Ann.*, **206**, 377 (1881); Wendt, *J. prakt. Chem.*, [2] **46**, 322 (1892).

590. Marchetti, *Gazz. chim. ital.*, **11**, 265,439 (1881); *Ber.*, **14**, 2241 (1881); *Ber.*, **15**, 251 (1882).

591. Günther and Krauch, German pat., 407,240, *Chem. Zentr.*, I, 1791 (1925).

592. Elbs and Christ, *J. prakt. Chem.*, [2] **106**, 17 (1923).

593*a*. Veselý and Štursa, *C.A.*, **25**, 4877 (1931). *b*. Steiger, *Helv. Chim. Acta*, **13**, 173 (1930).

594. Dziewoński and Waszkowski, *Bull. inter. acad. Polonaise*, 604 (1929A); *C.A.*, **25**, 1241 (1931).

595. Veselý, Štursa, Olejníček, and Rein, *C.A.*, **24**, 611 (1930).

596*a*. Dziewoński, Schoenowna, and Waldmann, *Ber.*, **58B**, 1211 (1925). *b*. Dziewoński and Wulffshon, *C.A.*, **25**, 1514 (1931). *c*. Levy, *Ann. chim.*, **9**, 5 (1938).

597. Weissgerber and Kurber, *Ber.*, **52B**, 346 (1919); Ges. für Teerverwertung, German pat., 301,079, *Chem. Zentr.*, II, 713 (1917).

598*a*. Weissgerber, *Ber.*, **52B**, 370 (1919). *b*. I. G. Farbenind. A.-G., French pats. 807,830 and 807,831, *C.A.*, **31**, 6023 (1937).

599. Giovanozzi, *Gazz. chim. ital.*, **12**, 147 (1882); *Ber.*, **15**, 1577 (1882).

600. Dachlauer and Thiel, U. S. pat., 1,804,527, *C.A.*, **25**, 3669 (1931).

601*a*. I. G. Farbenind. A.-G., British pat., 253,118, *C.A.*, **21**, 2477 (1927); British pat., 269.155, *C.A.*, **22**, 1365 (1928). *b*. Cook and Valjavec, U. S. pat., 2,133,282, *C.A.*, **33**, 646 (1939). *c*. Kimbara, British pat., 502,964, *C.A.*, **33**, 6997 (1939); see also British pat., 490,764, *C.A.*, **33**, 783 (1939).

602. Dziewoński and Dziecielewski, *C.A.*, **22**, 2164 (1928).

603*a*. Miquel, *Bull. soc. chim.*, [2] **26**, 5 (1876). *b*. Kahn and Thauss, U. S. pat., 1,781,981, *C.A.*, **25**, 968 (1931).

604. Kalle and Co., German pat., 248,994, *Chem. Zentr.*, II, 300 (1912); see also Holliday and Hodgkinson, British pat., 3,730 (1883).

605*a*. Oliveri-Mandelá, *Atti accad. Lincei*, **21**, I, 779 (1912); *C.A.*, **6**, 2748 (1912). *b*. Dziewoński and Stollyhwo, *C.A.*, **18**, 981 (1924); *Ber.*, **57B**, 1531 (1924).

606*a*. Dziewoński, Galitzerówna, and Kocwa, *C.A.*, **22**, 1154 (1928). *b*. Dziewoński and Kocwa, *C.A.*, **23**, 2435 (1929).

607. Dziewoński, Grünberg, and Schoen, *C.A.*, **25**, 5419 (1931).

608. Bogert and Conklin, *Collection Czechoslov. Chem. Communications*, **5**, 187 (1933); *C.A.*, **27**, 4230 (1933).

609. Armstrong and Wynne, *Chem. News*, **60**, 58 (1889).

610*a*. Zinin, *J. prakt. Chem.*, **33**, 36 (1844). *b*. Arnell, dissertation, Upsala, 1889, p. 9; *Bull. soc. chim.*, [2] **39**, 62 (1883); *Ber.*, **16**, 570 (1883); *Ber.*, **17R**, 47 (1884).

611*a*. Armstrong and Williamson, *Proc. Chem. Soc.*, 233 (1886); 145 (1887). *b*. Armstrong and Wynne, *Chem. News*, **61**, 285 (1890).

612. Vorozhtzov and Karlash, *C.A.*, 29, 2530 (1935).

613. Ferrero and Bolliger, *Helv. Chim. Acta*, **11**, 1144 (1928).

614. Oehler, German pat., 76,396, *Frdl.*, **4**, 523.

615. Armstrong and Wynne, *Chem. News*, **61**, 94 (1890).

616. Oehler, German pat., 76,230, *Frdl.*, **4**, 522.

617. Rudolph, German pat., 104,902, *Chem. Zentr.*, II, 1038 (1899).

618. Armstrong and Wynne, *Chem. News*, **73**, 55 (1896).

619. Arnell, *Bull. soc. chim.*, [2] **45**, 184 (1886).

620. Armstrong and Wynne, *Chem. News*, **55**, 91 (1887); Armstrong, *ibid.*, **58**, 295 (1888).

621. Armstrong and Wynne, *ibid.*, 60, 58 (1889).

622. Armstrong and Wynne, *ibid.*, **62**, 164 (1890).

623. Heller, *Chem. News*, 60, 58 (1889).

624. Dziewoński and Zakrzewska-Barnaowska, *C.A.*, **21**, 2682 (1927).

625. Dziewoński, Schoen, and Glazner, *C.A.*, **25**, 1518 (1931); Dziewoński, Glasnerówna, and Orzelski, *C.A.*, **18**, 981 (1924).

626*a*. Laurent, *Compt. rend.*, **31**, 537 (1850); *Ann.*, **72**, 298 (1849). *b*. Schmidt and Schaal, *Ber.*, **7**, 1369 (1874); Palmaer, *Ber.*, **21**, 3260 (1888). *c*. Erdmann, *Ann.*, **247**, 306 (1888). *d*. Armstrong and Williamson, *Chem. News*, **54**, 256 (1886); Tinker, U. S. pat., 2,143,963, *C.A.*, **33**, 2908 (1939).

627. Kappeler, *Ber.*, **45**, 633 (1912).

628. Meister, Lucius, and Brüning, German pat., 117,268, *Chem. Zentr.*, I, 286 (1901); Eckstein, *Ber.*, **35**, 3403 (1902).

629. A.-G. für Anilinfabrik, German pat., 103,980, *Chem. Zentr.*, II, 949 (1899).

630. Dziewoński and Orzelski, *C.A.*, **22**, 1160 (1928).

631. Battershall, *Ann.*, **168**, 119 (1873); Stumpf, *Ann.*, **188**, 1 (1877).

632. Royle and Schedler, *J. Chem. Soc.*, **123**, 1641 (1923).

633. Dutt, *Ber.*, **16**, 1251 (1883).

634. Armstrong and Williamson, *Chem. News*, **55**, 136 (1887).

635*a*. Butler and Royle, *J. Chem. Soc.*, **123**, 1650 (1923). *b*. Hill and Balls, *J. Am. Chem. Soc.*, **44**, 2051 (1922).

636. Moro, *Gazz. chim. ital.*, **26**, I, 114 (1896).

637*a*. Anselm and Zuckmayer, *Ber.*, **32**, 3283 (1899); Bargellini, *Atti accad. Lincei*, [5] **14**, II, 689 (1905); *Gazz. chim. ital.*, **36**, II, 107 (1906). *b*. Ioffe and Naumova, *J. Gen. Chem.*, **9**, 1121 (1939); *C.A.*, **33**, 8605 (1939).

638*a*. Conrad and Fischer, *Ann.*, **273**, 105 (1893). *b*. Friedlander and Taussig, *Ber.*, **30**, 1459 (1897).

639*a*. Schaeffer, *Ann.*, **152**, 293 (1869); *Ber.*, **2**, 93 (1869); *J. prakt. Chem.*, **106**, 465 (1869). *b*. Claus and Oehler, *Ber.*, **15**, 312 (1882). *c*. Bender, *Ber.*,

22, 993 (1889). *d.* Liebmann and Studer, German pat. appl., 4,327, *Frdl.*, I, 392.

640*a*. Witt, *Ber.*, **24**, 3157 (1891). *b.* Verein Chem. Fabrik Mannheim, German pat., 26,012, *Frdl.*, **1**, 391. *c.* Bayer & Co., German pat., 237,396, *Chem. Zentr.*, II, 651 (1911).

641. Holdermann, *Ber.*, **39**, 1255 (1906).

642. Baum, German pat. appl., 4,197, *Frdl.*, **1**, 390; Claus and Knyrim, *Ber.*, **18**, 2924 (1889).

643. Pollak, Gebauer-Fülnegg, Blumenstock-Halward, and Petertil, *Monatsh.*, **49**, 187 (1928).

644. Baddiley, Payman, and Bainbridge, British pat., 186,515, *C.A.*, **17**, 289 (1923).

645. Gebauer-Fülnegg, and Glückmann, *Monatsh.*, **53–54**, 100 (1929).

646. Vignon and Co., German pat., 32,291, *Frdl.*, **1**, 393.

647. Claus and Mielcke, *Ber.*, **19**, 1182 (1886).

648. Badische Anilin- und Sodafabrik, German pat., 10,785, *Frdl.*, **1**, 328; Lauterbach, *Ber.*, **14**, 2028 (1881).

649*a*. Bayer and Co., German pat., 68,344, *Frdl.*, **3**, 667. *b.* Bernthsen, *Ber.*, **23**, 3091 (1890); Badische Anilin- und Sodafabrik, German pat., 57,388, *Frdl.*, **2**, 260. *c.* Kalle and Co., A.-G., German pat., 343,056, *C.A.*, **17**, 1247 (1923).

650*a*. Gebauer-Fülnegg, and Haemmerle, *J. Am. Chem. Soc.*, **53**, 2648 (1931). *b.* Badische Anilin- und Sodafabrik, German pat., 55,094, *Frdl.*, **2**, 257.

651*a*. Armstrong, *Ber.*, **15**, 202 (1882); Nietzki, *Ber.*, **15**, 305 (1882). *b.* Armstrong and Wynne, *Chem. News*, **73**, 54 (1896). *c.* Tobias, German pat., 74,688, *Frdl.*, **3**, 440. *d.* Vorontzov and Sokolova, *Org. Chem. Ind.*, (*U.S.S.R.*), **2**, 399 (1936). *e.* Vorontzov and Ivanova, *J. Applied Chem.* (*U.S.S.R.*), **13**, 1470 (1940); *C.A.*, **35**, 4007 (1941).

652. Bayer and Co., German pat., 26,673, *Frdl.*, **1**, 369; German pat., 18,027, *Frdl.*, **1**, 364; Höchster Farbwerke, German pat., 36,491, *Frdl.*, **1**, 381; Leonhardt and Co., and Schulz, German pat., 33,857, *Frdl.*, **1**, 375; Maxim, German pat., 293,982, *Chem. Zentr.*, II, 619 (1916).

653. Green, *J. Chem. Soc.*, **55**, 37 (1889); *Ber.*, **22**, 724 (1889).

654. Engel, *J. Am. Chem. Soc.*, **52**, 2835 (1920); Crossley and Simpson, U. S. pat., 1,570,046.

655*a*. Pollak, Gebauer-Fülnegg, and Blumenstock-Halward, *Monatsh.*, **53–54**, 83 (1929). *b.* Dziewoński and Loewenhof, *C.A.*, **22**, 2560 (1928).

656. Tinker and Hansen, U. S. pat., 1,934,216, *C.A.*, **28**, 495 (1934).

657. Parmalee, U. S. pat., 1,662,396, *C.A.*, **22**, 1365 (1928).

658. Vorontzov, *C.A.*, **29**, 2530 (1935).

659. Cotton, U. S. pat., 1,913,748, *C.A.*, **27**, 4248 (1933).

660. Griess, *Ber.*, **13**, 1956 (1880); Höchster Farbwerke, German pat., 3,229, *Frdl.*, **1**, 351, 377.

661. Leipziger Anilinfabrik, German pat., 33,916, *Frdl.*, **1**, 383.

662. Höchster Farbwerke, German pat., 36,491, *Frdl.*, **1**, 381.

663. Kawaguchi, *J. Chem. Ind.* (*Japan*), **26**, 1233 (1923); *C.A.*, **18**, 2891 (1924).

664. Helfaer, U. S. pat., 1,880,442, *C.A.*, **27**, 515 (1933).

665. Vorontzov and Sokolova, *C.A.*, **28**, 3730 (1934); **31**, 7053 (1937).

666. Baum, German pat. appl., 4,199, *Frdl.*, **1**, 384.

667. Armstrong and Wynne, *Chem. News*, **61**, 93 (1890).

668. Lewinstein, *Ber.*, **16**, 462 (1883); Limpach, *Ber.*, **16**, 726 (1883); Höchster Farbwerke, German pat., 22,038, *Frdl.*, **1**, 387.

669. Anschütz, *Ann.*, **415**, 95 (1918); see, however, Nietzki, *Chem.-Ztg.*, **15**, 296 (1891).

670. Weinberg, *Ber.*, **20**, 2907 (1887); Cassella and Co., German pat., 42,112, *Frdl.*, **1**, 376; German pat., 45,221, *Frdl.*, **2**, 246; Dressel and Kothe, *Ber.*, **27**, 1206 (1894); Bayer and Co., German pat., 77,596, *Frdl.*, **4**, 536.

671. Pollak and Blumenstock-Halward with co-workers, *Monatsh.*, 49, 203 (1928).

672. Pollak, Gebauer-Fülnegg, and Blumenstock-Halward, *ibid.*, **53–54**, 83 (1929).

673. Witt and Schneider, *Ber.*, **34**, 3178 (1901).

674*a*. Maikopar, *J. Russ. Phys.-Chem. Soc.*, 2, 126 (1870). *b*. Heermann, *J. prakt. Chem.*, [2] **49**, 130 (1894).

675. Percival, *Chem. News*, **59**, 226 (1889).

676. Lapworth, *ibid.*, **71**, 206 (1895).

677. Amphlett and Armstrong, *Proc. Chem. Soc.*, 147 (1887).

678. Reverdin, *Ber.*, **27**, 3460 (1894); Höchster Farbwerke, German pat., 80,889, *Frdl.*, **4**, 525.

679. Höchster Farbwerke, German pat., 80,888, *Frdl.*, **4**, 523.

680*a*. Armstrong and Graham, *J. Chem. Soc.*, **39**, 137 (1881); *Ber.*, **14**, 1286 (1881). *b*. Armstrong, *Ber.*, **15**, 206 (1882). *c*. Armstrong and Rossiter, *Chem. News*, **59**, 226 (1889). *d*. *Ber.*, **24R**, 719 (1891).

681. Armstrong and Davis, *Chem. News*, **74**, 301 (1896).

682*a*. Friedlander, *Ber.*, **28**, 1948 (1895). *b*. Ullmann and Denzler, *Ber.*, **39**, 4339 (1907).

683. König, *Ber.*, **22**, 787 (1889); Dahl and Co., German pat., 51,715, *Frdl.*, **2**, 261.

684. Seidler, German pat., 56,328, *Frdl.*, **2**, 263.

685. Seidler, German pat., 53,343, *Frdl.*, **2**, 248.

686. Schmid, *Ber.*, **26**, 1115 (1893); Hirsch, *Ber.*, **26**, 1177 (1893); Hosaeus, *Ber.*, **26**, 671 (1893); Ges. Chem. Ind. Basel, German pat., 69,357, *Frdl.*, **3**, 506; Bucherer, *Chem. Zentr.*, II, 42 (1903).

687*a*. Heller, *Ber.*, **45**, 675 (1912). *b*. Anselm and Zuckmayer, *Ber.*, **32**, 3295 (1899). *c*. I. G. Farbenind. A.-G., British pat., 291,965, *C.A.*, **23**, 1139 (1929).

688. A.-G. für Anilinfabrik, German pat., 75,142, *Frdl.*, **3**, 492; Griess, *Ber.*, **13**, 1959 (1880); Weber, *Ber.*, **14**, 2206 (1881); German pat., 77,552, *Frdl.*, **4**, 1065.

689. Fieser and Lothrop, *J. Am. Chem. Soc.*, **57**, 1459 (1935).

690. Bayer and Co., German pat., 72,222, *Frdl.*, **3**, 493; Jacchia, *Ann.*, **323**, 114, 131 (1902).

691. Badische Anilin- und Sodafabrik, German pat., 79,029, *Frdl.*, **4**, 759.

692. Bucherer and Uhlmann, *J. prakt. Chem.*, [2] **80**, 235 (1909); Ewer and Pick, German pat., 41,934, *Frdl.*, **1**, 398.

693. Bayer and Co., German pat., 10,867, *Frdl.*, **3**, 503; Witt and Kaufmann, *Ber.*, **24**, 3163 (1891).

694. A.-G. für Anilinfabrik, German pat., 99,759, *Frdl.*, **5**, 174.

695. Ges. Chem. Ind. Basel, German pat., 69,357, *Frdl.*, **3**, 506.

696. Paal and Jänicke, *Ber.*, **28**, 3164 (1895); de Ruijter de Wildt, *Rec. trav. chim.*, **23**, 175 (1904).

697. Tobias, German pat., 79,132, *Frdl.*, **4**, 527; see also Vorozhtzov, Kozlov, Aristov, Baryshev, and Fedulov, *J. Gen. Chem.* (*U.S.S.R.*), 10, 894 (1940).

698. Landshoff and Meyer, German pat., 56,563, *Frdl.*, **2**, 269; Cleve, *Ber.*, **24**, 3472 (1891); Erdmann, *Ann.*, **275**, 226 (1893).
699. Bayer and Co., German pat., 72,833, *Frdl.*, **3**, 427.
700. Bayer and Co., German pats., 75,319 and 77,118, *Frdl.*, **3**, 428, 429.
701*a*. Nevile and Winther, *Ber.*, **13**, 1948 (1880). *b*. Witt, *Ber.*, **19**, 56 (1886). *c*. Lenkhold and Nikiforov, *Org. Chem. Ind.* (*U.S.S.R.*), **2**, 285 (1936); *C.A.*, **31**, 1794 (1937).
702. Bischoff, *Ber.*, **23**, 1912 (1890).
703*a*. Langguth, *Chimie et industrie*, **24**, 31 (1930). *b*. Lenkhol'd and Safronenko, *J. Applied Chem.* (*U.S.S.R.*), **11**, 286 (1938); *C.A.*, **32**, 5821 (1938).
704*a*. Schmidt and Schaal, *Ber.*, **7**, 1368 (1874). *b*. Cleve, *Bull. soc. chim.*, [2] **26**, 241 (1876); *Ber.*, **10**, 1722 (1877). *c*. Schultz, *Ber.*, **20**, 3158 (1887). *d*. Witt, *Ber.*, **19**, 578, 1720 (1886). *e*. Erdmann, *Ann.*, **247**, 306 (1888).
705. Erdmann, *Ber.*, **20**, 3185 (1887); Mauzelius, *Ber.*, **20**, 3401 (1887).
706. Hirsch, *Ber.*, **21**, 2371 (1888); Nölting, *Z. Chem.*, 1212 (1888); Dahl and Co., German pat., 42,440, *Frdl.*, **1**, 411; Vorontzov, *C.A.*, **26**, 4599 (1932).
707. Corbellini, *Giorn. chim. ind. applicata*, **9**, 355 (1927); *C.A.*, **22**, 1972 (1928).
708. Dahl and Co., German pat., 41,957, *Frdl.*, **1**, 407.
709. Armstrong and Wynne, *Chem. News*, **62**, 162 (1890).
710. Meister, Lucius, and Brüning, German pat., 22,545, *Frdl.*, **1**, 331.
711. Tobias, *Ber.*, **23**, 1628 (1890).
712. Armstrong and Wynne, *Chem. News*, **73**, 55 (1896).
713. Badische Anilin- und Sodafabrik, German pat., 69,555, *Frdl.*, **3**, 433.
714. Cassella and Co., German pat., 188,505, *Chem. Zentr.*, II, 1467 (1907).
715. Cassella and Co., German pat. appl., 4,021, *Frdl.*, **3**, 432.
716. Bayer and Co., German pat. appl., 7,016, *Frdl.*, **3**, 434.
717. Cassella and Co., German pat. appl., 3,939, *Frdl.*, **3**, 432.
718. Schoelkopf, German pat., 40,571, *Frdl.*, **1**, 394; Bernthsen, *Ber.*, **22**, 3327 (1889); **23**, 3088 (1890).
719. Wahl and Vermeylen, *Compt. rend.*, **184**, 334 (1927); *Bull. soc. chim.*, **41**, 514 (1927).
720. Bayer and Co., German pat., 75,084, *Frdl.*, **3**, 430; 80,853, *Frdl.*, **4**, 555.
721. A.-G. für Anilinfabrik, German pat. appl., 3,346, *Frdl.*, **3**, 470.
722*a*. Bayer and Co., German pat., 79,566, *Frdl.*, **4**, 530; 84,139, *Frdl.*, **4**, 532. *b*. Dressel and Kothe, *Ber.*, **27**, 2147 (1894).
723. Tinker and Hansen, U. S. pat., 1,969,189, *C.A.*, **28**, 6160 (1934).
724. Green and Vakil, *J. Chem. Soc.*, **113**, 40 (1918).
725. Dahl and Co., German pat., 32,276, *Frdl.*, **1**, 425.
726. Green, *J. Chem. Soc.*, **55**, 35 (1889); *Ber.*, **22**, 722 (1889); Dahl and Co., German pat., 29,084, *Frdl.*, **1**, 421.
727. Waterman and Groot, *Chem. Weekblad*, **25**, 40 (1928).
728. Levi, *Giorn. chim. ind. applicata*, **3**, 97 (1921); *C.A.*, **15**, 2864 (1921).
729. Forsling, *Ber.*, **19**, 1715 (1886); *Ber.*, **20**, 2099 (1887); Bayer and Duisberg, *Ber.*, **20**, 1428 (1887); Erdmann, *Ber.*, **21**, 639 (1888); Weinberg, *Ber.*, **20**, 2909, 3353 (1887); Armstrong and Wynne, *Chem. News*, **59**, 188 (1889); Bayer and Co., German pat., 39,925, *Frdl.*, **1**, 427; 41,505, *Frdl.*, **1**, 428.
730. Liebmann, German pat. appl., 3,205, *Frdl.*, **1**, 420.
731. Dahl and Co., German pat., 32,271, *Frdl.*, **1**, 424.
732. Voronkov, *Chem. Zentr.*, I, 2174 (1932); *C.A.*, **27**, 5737 (1933).

733. Bayer and Co., German pats., 42,272 and 42,273, *Frdl.*, **1**, 429, 430; Weinberg, *Ber.*, **20**, 3354 (1887).

734. Gans and Co., German pat., 35,019, *Frdl.*, **1**, 382; Armstrong and Wynne, *Chem. News*, **61**, 92 (1890).

735. Fierz-David and Braunschweig, *Helv. Chim. Acta*, **6**, 1146 (1923); see also Ofitzerov, *C.A.*, **29**, 1086, 2530 (1935).

736. Bayer and Co., German pat., 80,878, *Frdl.*, **4**, 542.

737. Bucherer and Wahl, *J. prakt. Chem.*, [2] **103**, 129 (1921).

738. Forsling, *Ber.*, **21**, 3495 (1888).

739. Dressel and Kothe, *Ber.*, **27**, 1194 (1894); Bayer and Co., German pat., 79,243, *Frdl.*, **4**, 541.

740. Dressel and Kothe, *Ber.*, **27**, 1202 (1894); Bayer and Co., German pat., 81,762, *Frdl.*, **4**, 542.

741. Bayer and Co., German pat., 90,489, *Frdl.*, **4**, 546.

742. Morgan and Mitchell, *J. Chem. Soc.*, 1910 (1932).

743*a*. Sieglitz, German pat., 654,083, *C.A.*, **32**, 2145 (1938). *b*. Fleischer and Schranz, *Ber.*, **55**, 3253 (1922); Lander, German pat., 669,809, *C.A.*, **33**, 5416 (1939); Morgan and Yarsley, *J. Soc. Chem. Ind.*, **44**, 513T (1925); I. G. Farbenind. A.-G., French pats., 807,842 and 807,843, *C.A.*, **31**, 6023 (1937).

744. Herzberg and Lange, U. S. pat., 1,785,955, *C.A.*, **25**, 524 (1931).

745*a*. Kalle and Co., German pat., 90,274, *Frdl.*, **4**, 603. *b*. Friedländer and Welmans, *Ber.*, **21**, 3128 (1888). *c*. Fussgänger, *Ber.*, **35**, 976 (1902).

746*a*. Smith, *J. Chem. Soc.*, **41**, 182 (1882). *b*. Leonhardt and Co., German pat., 95,624, *Frdl.*, **4**, 1001.

747. Schweitzer and Burr, U. S. pat., 1,939,025, *C.A.*, **28**, 1361 (1934).

748. Lesser, *Ber.*, **27**, 2364 (1894); Clayton Aniline Co., German pat., 53,649, *Frdl.*, **2**, 266; 57,370, *Frdl.*, **3**, 512; Bayer and Co., German pat., 70,349, *Frdl.*, **3**, 513.

749*a*. Lange, *Ber.*, **20**, 2940 (1887); Ewer and Pick, German pat., 42,784, *Frdl.*, **1**, 406. *b*. I. G. Farbenind. A.-G., German pat., 673,730, *C.A.*, **33**, 6484 (1939).

750. Kinzelberger and Co., German pat. appl., 5,732, *Frdl.*, **1**, 431; Ufimtzev, *Ber.*, **69B**, 2188 (1936).

751. Höchster Farbwerke, German pat., 292,357, *Chem. Zentr.*, II, 81 (1916).

752. Badische Anilin- und Sodafabrik, German pat., 112,778, *ibid.*, II, 511 (1900).

753. Badische Anilin- und Sodafabrik, German pat., 153,298, *ibid.*, II, 750 (1904).

754. Armstrong and Wynne, *Chem. News*, **59**, 141, 188 (1889).

755. Hellstrom, *Öfersigt af K. Vetenskaps-Akademiens förhandlingar* (*Stockholm*), **2**, 107 (1889).

756. Badische Anilin- und Sodafabrik, German pat., 84,951, *Frdl.*, **4**, 554; 54,662, *Frdl.*, **2**, 400; 77,937, *Frdl.*, **4**, 552.

757. Badische Anilin- und Sodafabrik, German pat., 82,900, *Frdl.*, **4**, 552.

758. Badische Anilin- und Sodafabrik, German pat., 62,289, *Frdl.*, **3**, 458.

759. Badische Anilin- und Sodafabrik, German pat., 125,696, *Chem. Zentr.*, II, 1187 (1901).

760. Cassella and Co., German pat., 108,848, *ibid.*, I, 1214 (1900).

761. Bayer and Co., German pat., 216,075, *ibid.*, II, 1950 (1909).

762. Cassella and Co., German pat., 72,584, *Frdl.*, **3**, 472.

763. Bucherer and Uhlmann, *J. prakt. Chem.*, [2] **80**, 213 (1909).

764. Dahl and Co., German pat., 66,354, *Frdl.*, **3**, 498.

765. Bayer and Co., German pat., 251,695, *Chem. Zentr.*, II, 1413 (1912).

766. Battegay and Brandt, *Bull. soc. chim.*, **33**, 1667 (1923).

767. See Battegay and Brandt, *ibid.*, **31**, 910 (1922) for nitration experiments.

768*a*. Soc. St. Denis, German pats., 72,226, *Frdl.*, **3**, 195; 77,311, *Frdl.*, **4**, 271. *b*. Martinet, *Rev. gén. mat. color*, **25**, 4951 (1921); *C.A.*, **15**, 2640 (1921).

769*a*. Liebermann and Boeck, *Ber.*, **11**, 1613 (1878); Liebermann, *Ber.*, **12**, 182 (1879). *b*. Soc. St. Denis, German pat., 73,961, *Frdl.*, **3**, 196; 76,280, *Frdl.*, **4**, 270.

770. A.-G. für Anilinfabrik, German pat., 21,178, *Frdl.*, **1**, 538; Schüler, *Ber.*, **15**, 1807 (1882); Schmidt and Tust, *Ber.*, **37**, 70 (1904); Dienel, *Ber.*, **38**, 2863 (1905); Lampe, *Ber.*, **42**, 1413 (1909); Liebermann and Bischoff, *Ber.*, **13**, 47 (1880); Liebermann, *Ann.*, **212**, 45 (1882).

771. Bach, *Ber.*, **23**, 1570 (1890).

772. Badische Anilin- und Sodafabrik, German pat., 260,562, *Chem. Zentr.*, II, 104 (1913).

773. Minaev and Federov, *C.A.*, **25**, 4258 (1931).

774. Höchster Farbwerke, German pat., 292,590, *Chem. Zentr.*, II, 208 (1916).

775*a*. Perkin, *Ann.*, **158**, 320 (1871). *b*. Behla, *Ber.*, **20**, 706 (1887).

776*a*. Lauer, *J. prakt. Chem.*, [2] **135**, 361 (1933). *b*. Schwenk and Waldmann, *Z. angew. Chem.*, **45**, 17 (1932); German pat., 576,444, *C.A.*, **27**, 3722 (1933); U. S. pat., 1,890,866, *C.A.*, 27, 1642 (1933); Gublemann and Rintelman, U. S. pat., 1,899,957, *C.A.*, 27, 2965 (1933).

777*a*. Coppens, *Rec. trav. chim.*, **44**, 907 (1925). *b*. Lauer, *J. prakt. Chem.*, [2] **130**, 185 (1931). *c*. *ibid.*, **137**, 161 (1933).

778. See Meyer-Jacobsen, *Lehrbuch der organischen Chemie*, Vol. II, Part 2, p. 569, for a discussion of older patent literature.

779*a*. Graebe and Liebermann, *Ann.*, **160**, 131 (1871). *b*. Dünschmann, *Ber.*, **37**, 332 (1904). *c*. Lauer and Oda, *J. prakt. Chem.*, [2] **142**, 258 (1935); Oda and Tamura, *Bull. Inst. Phys.-Chem. Research (Tokyo)*, **16**, 921 (1937); *C.A.*, **32**, 5631 (1938).

780. Caro, *Ber.*, **9**, 681 (1876); Liebermann and Pleus, *Ber.*, **37**, 647 (1904); Maxim, German pat., 293,982, *Chem. Zentr.*, II, 619 (1916).

781*a*. Fierz-David, Krebser, and Anderau, *Helv. Chim. Acta*, **10**, 197 (1927). *b*. Fierz-David, *ibid.*, **11**, 197 (1928).

782. See also *a*. Crossley, *J. Am. Chem. Soc.*, **37**, 2178 (1915). *b*. Segui, *C.A.*, **28**, 7257 (1934). *c*. Beretta and Gallotti, *Ann. chim. applicata*, **22**, 272 (1932); *C.A.*, 26, 5944 (1932).

783*a*. Schwenk, *Z. angew. Chem.*, **44**, 912 (1931). *b*. Lauer and Oda, *Ber.*, **70B**, 333 (1937).

784*a*. Iljinski, *Ber.*, **36**, 4197 (1903). *b*. Schmidt, *Ber.*, **37**, 67 (1904). *c*. Bayer and Co., German pat., 149,801, *Chem. Zentr.*, I, 1043 (1904).

785. Thümmler, German pat., 214,156, *ibid.*, II, 1396 (1909).

786. Goodrich and Gubelmann, U. S. pat., 1,881,498, *C.A.*, **27**, 515 (1933).

787. Roux and Martinet, *Compt. rend.*, **172**, 385 (1921).

788. Clough, *J. Soc. Dyers Colorists*, **38**, 299 (1922); *C.A.*, **17**, 1637 (1923).

789. Meyer, *Compt. rend.*, **184**, 609 (1927); **188**, 519 (1926); *Bull. soc. chim.*, **41**, 1627 (1927).

790. Crossley, *J. Am. Chem. Soc.*, **39**, 122 (1917).

791. Rogers, U. S. pat., 1,963,383, *C.A.*, **28**, 5079 (1934).

792. Gubelmann, Goodrich, and Rintelman, U. S. pat., 1,870,249, *C.A.*, **26**, 5577 (1932).

793. Griffin, U. S. pat., 1,260,535, *C.A.*, **12**, 1469 (1918); see also Vernet and Rauch, U. S. pat., 1,437,571, *C.A.*, **17**, 771 (1923).

794. Bayer and Co., German pat., 157,123, *Chem. Zentr.*, I, 57 (1905).

795. Wedekind and Co., German pat., 170,329, *Chem. Zentr.*, I, 1719 (1906).

796. Bayer and Co., German pats., 162,035, *Chem. Zentr.*, II, 864 (1905); 172,688, *ibid.*, II, 646 (1906); 155,045, *ibid.*, II, 1270 (1904); Badische Anilin- und Sodafabrik, German pats., 153,129, *ibid.*, II, 751 (1904); 154,337, *ibid.*, II, 1080 (1904); Höchster Farbwerke, German pat., 158,413, *ibid.*, I, 704 (1905).

797. Locher and Fierz, *Helv. Chim. Acta*, **10**, 642 (1927).

798. Goldberg, *J. Chem. Soc.*, 1771 (1931).

799. Walsh and Weizmann, *J. Chem. Soc.*, **97**, 688 (1910).

800. Schilling, *Ber.*, **46**, 1066 (1913).

801. Kircher, *Ann.*, **238**, 349 (1887).

802*a*. Adamson, U. S. pat., 1,965,818, *C.A.*, **28**, 5473 (1934). *b*. Claus and Engelsing, *Ber.*, **16**, 903 (1883). *c*. Gubelmann, Weiland, and Stallmann, U. S. pat., 1,810,010, *C.A.*, **25**, 4559 (1931).

803. Bayer and Co., German pat., 105,567, *Chem. Zentr.*, I, 320 (1900).

804. Bayer and Co., German pat., 258,517, *ibid.*, I, 1556 (1913).

805. Perkin and Cope, *J. Chem. Soc.*, **65**, 844 (1894).

806. Graebe, *Ann.*, **349**, 206 (1906).

807. Bayer and Co., German pat., 172,688, *Chem. Zentr.*, II, 646 (1906).

808*a*. Weinand, U. S. pat., 1,841,997, *C.A.*, **26**, 1623 (1932). *b*. Ogilvie and Hoare, U. S. pat., 2,251,688, *C.A.*, **35**, 6979 (1941).

809. Chemische Fabrik vorm. Sandoz, German pat., 530,135, *C.A.*, **25**, 5178 (1931); Peter, U. S. pat., 1,871,466, *C.A.*, **26**, 5971 (1932).

810. Badische Anilin- und Sodafabrik, German pat., 138.134, *Chem. Zentr.*, I, 209 (1903).

811. Bayer and Co., German pat., 164,727, *Chem. Zentr.*, II, 1703 (1905); 155,440, *ibid.*, II, 1356 (1904).

812. Bayer and Co., German pat., 84,509, *Frdl.*, **4**, 325.

813. Badische Anilin- und Sodafabrik, German pat., 121,684, *Chem. Zentr.*, II, 77 (1901).

814*a*. Graebe, *Ann.*, **167**, 152 (1873). *b*. Werner and co-workers, *Ann.*, **321**, 248 (1902). *c*. Sandqvist, dissertation, Upsala, 1912; *Ann.*, **392**, 76 (1912). *d*. Fieser, *J. Am. Chem. Soc.*, **51**, 2460 (1929). *e*. Ioffe, *Org. Chem. Ind. (U.S.S.R.)*, **7**, 374 (1940); *C.A.*, **35**, 4009 (1941). *f*. Fieser, *Org. Syntheses*, **16**, 63 (1936).

815. Ioffe, *J. Gen. Chem. (U.S.S.R.)*, **3**, 448 (1933); *C.A.*, **28**, 1694 (1934); Kheĭfets, *C.A.*, **33**, 9317 (1939).

816. Ioffe and Matveeva, Russian pat., 34,550, *C.A.*, **29**, 2977 (1935).

817. Pschorr and Klein, *Ber.*, **34**, 4004 (1901).

818. Fischer, *Ber.*, **13**, 314 (1880); Rehs, *Ber.*, **10**, 1252 (1877).

819*a*. Fieser, *J. Am. Chem. Soc.*, **51**, 2471 (1929). *b*. Komppa and Wahlforss, *ibid.*, **52**, 5013 (1930). *c*. Fieser and Young, *ibid.*, **53**, 4120 (1931); Hasselstrom and Bogert, *ibid.*, **57**, 1580 (1925).

820. Ekstrand, *Ann.*, **185**, 86 (1877); Fritzsche, *J. prakt. Chem.*, [1] **82**, 333 (1861).

821. Arnot, German pat., **315**,623, *Chem. Zentr.*, II, 188 (1920).

822*a*. Anschütz and Siemienski, *Ber.*, **13**, 1179 (1880). *b*. Sandqvist, *Ann.*, **398**, 125 (1913). *c*. *Ann.*, **417**, 17 (1918).

823. Sandqvist, *Ber.*, **48**, 2054 (1915); *Kolloid-Z.*, **19**, 113 (1916); *Ber.*, **50**, **774** (1917); Lehman, *Ann. Physik.*, **55**, 81 (1918).

824. Sandqvist, *C.A.*, **14**, 1974 (1920).

825. Schmidt and Lumpp, *Ber.*, **41**, 4224 (1908).

826. Schmidt and Junghans, *Ber.*, **37**, 3564 (1904).

827. Mukherjee and Watson, *J. Chem. Soc.*, **109**, 620 (1916).

828. Rădulescu, *Z. physik. Chem.*, Abt. B, **5**, 301 (1929).

829. Courtot and Geoffrey, *Compt. rend.*, **178**, 2259 (1924).

830. Hodgkinson and Matthews, *J. Chem. Soc.*, **43**, 166 (1883).

831. Barbier, *Ann. chim. phys.*, [5] **7**, 472 (1876).

832. Schmidt, Retzlaff, and Haid, *Ann.*, **390**, 217 (1912); Courtot and Geoffrey, *Compt. rend.*, **180**, 1665 (1925).

833. Schmidt and Schultz, *Ann.*, **207**, 345 (1881).

834. Schroeter, Müller, and Huang, *Ber.*, **62B**, 645 (1929).

835. Henke and Weiland, U. S. pat., 1,853,352, *C.A.*, **26**, 3264 (1932).

836. Gubelmann and Henke, U. S. pat., 1,853,348, *C.A.*, **26**, 3264 (1932).

837. Goldschmiedt, *Monatsh.*, **1**, 227 (1880).

838. Goldschmiedt and Wegscheider, *ibid.*, **4**, 237 (1883).

839*a*. Mellin, *Ber.*, **23**, 2536 (1890). *b*. Vollmann, Becker, Corell, Streeck, and Langbein, *Ann.*, **531**, 1–159 (1937). *c*. Tietze and Bayer, *Ann.*, **540**, 189 (1939). *d*. Soc. pour l'ind. chim. à Bâle, British pat., 469,927, *C.A.*, **32**, 596 (1938).

840*a*. Smith, *J. Chem. Soc.*, **32**, 558 (1877); Smith and Takamatsu, *ibid.*, **39**, 551 (1881). *b*. Ioffe, Kuznetsov, and Panov, *J. Gen. Chem.* (*U.S.S.R.*), 6, 999 (1936); *C.A.*, **31**, 675 (1937).

841. Dziewoński and Pochwalski, *C.A.*, **18**, 982 (1924).

842*a*. Heller, *Ber.*, **45**, 673 (1912). *b*. Lauer and Oda, *Ber.*, **70B**, 1707 (1937). *c*. Ioffe and Mel'teva, *J. Gen. Chem.* (*U.S.S.R.*), 9, 1104, 1121 (1939). *d*. Pritchard and Simonsen, *J. Chem. Soc.*, 2047 (1938).

843*a*. Deichler and Weizmann, *Ber.*, **36**, 724 (1903); see also German pats., 134,985, *Chem. Zentr.*, II, 1085 (1902); 138,325, *Frdl.*, **7**, 241. *b*. Ioffe and Fedorova, *J. Gen. Chem.* (*U.S.S.R.*), **11**, 619 (1941); *C.A.*, **35**, 6952 (1941).

844. Heller and Schülke, *Ber.*, **41**, 3634 (1908); Sempronj, *Gazz. chim. ital.*, 69, 448 (1939); Ioffe and Kashnitskaya, *J. Gen. Chem.*, 9, 1124 (1939); *C.A.*, **33**, 8605 (1939).

845. Bentley, Friedl, Thomas, and Weizmann, *J. Chem. Soc.*, **91**, 425 (1907).

846. Graebe and Peter, *Ann.*, **340**, 265 (1905).

847*a*. Adler, *Ber.*, **12**, 1889 (1879); Liebermann, *Ann.*, **158**, 311 (1871). *b*. I. G. Farbenind. A.-G., French pat., 782,756, *C.A.*, **29**, 6906 (1935). *c*. Kern, U. S. pat., 2,134,446, *C.A.*, **33**, 646 (1939).

848. Pongratz, *Monatsh.*, **48**, 639 (1927).

849. Schwanert, *Ann.*, **116**, 268 (1860); Hill and Palmer, *Am. Chem. J.*, **10**, 373 (1888).

850*a*. Hill and Jennings, *ibid.*, **15**, 174 (1893). *b*. Hill and Sylvester, *ibid.*, **32**, 188 (1904). *c*. Gilman, Calloway, and Smith, *J. Am. Chem. Soc.*, **56**, **220** (1934); see also Straley, *Iowa State Coll. J. Sci.*, **11**, 115 (1936).

851. Hill and Hendrixson, *Am. Chem. J.*, **15**, 145 (1893); Hill and Jackson, *ibid.*, **12**, 116 (1890).

852. Wolff and Fertig, *Ann.*, **312**, 169 (1900).
853. Hoenig, *Ber.*, **18**, 3453 (1885); Tcherniac, *J. Chem. Soc.*, **109**, 1242 (1916).
854. Gilman, Smith, and Oatfield, *J. Am. Chem. Soc.*, **56**, 1412 (1934).
855. Hoffmeister, *Ann.*, **159**, 191 (1871).
856. Zehenter, *J. prakt. Chem.*, [2] **131**, 331 (1931).
857. Borsche and Schacke, *Ber.*, **56**, 2498 (1923).
858*a*. Mailhe, *Compt. rend.*, **154**, 1515 (1912). *b*. *Bull. soc. chim.*, **11**, 1011 (1912).
859. Epstein, *J. prakt. Chem.*, [2] **81**, 88 (1910).
860. Graebe, Knecht, and Unzeitig, *Ann.*, **209**, 138 (1881).
861. Hodgkinson and Limpach, *J. Chem. Soc.*, **59**, 1097 (1891).
862. Perkin, *ibid.*, **24**, 49 (1871); **28**, 14 (1875).
863. Sen and Chakravarti, *J. Indian Chem. Soc.*, **5**, 433 (1928).
864. Krüger, *Ber.*, **56B**, 480 (1923).
865. Curatolo, *Gazz. chim. ital.*, **14**, 257 (1884).
866. Richter, *J. prakt. Chem.*, [2] **28**, 302 (1883).
867. Boes, *Apoth. Ztg.*, **17**, 422 (1902).
868. Benedikt and Hazura, *Monatsh.*, **5**, 670 (1884); Herzig, *ibid.*, **17**, 426 (1896); Watson and Sen, *J. Chem. Soc.*, **106**, 393 (1914).
869. Perkin, *ibid.*, **43**, 192 (1883).
870. v. Liebig, *J. prakt. Chem.*, [2] **85**, 255 (1912); Durand, Huguenin and Co., German pat., 244,652, *Frdl.*, **10**, 236; *Chem. Zentr.*, I, 1066 (1912).
871*a*. Komppa, *J. prakt. Chem.*, [2] **122**, 319 (1929). *b*. Courtot, *Compt. rend.*, **198**, 2260 (1934).
872*a*. J. R. Geigy, A.-G., Swiss pats., 193,223–193,230, *C.A.*, **32**, 4250 (1938). *b*. Martinet and Dornier, *Compt. rend.*, **172**, 330 (1921).
873. Crum, *Jahresbericht*, **4**, 189 (1825); Berzelius, *ibid.*, **7**, 262 (1828); Joss, *ibid.*, **14**, 316 (1835); Dumas, *Ann.*, **22**, 73 (1837); **48**, 338 (1843); Schlieper, *Ann.*, **120**, 1 (1861); Vogel, *Ber.*, **11**, 1365 (1878); Heymann, *Ber.*, **24**, 1476 (1891); Juillard, *Bull. soc. chim.*, **7**, 619 (1892); Hönig, *Chem. Zentr.*, II, 1052 (1899); Eder, *Monatsh.*, **24**, 15 (1903); Heiduschka, *Arch. Pharm.*, **244**, 569 (1906); Tauber, *Chem. Ztg.*, **33**, 418 (1909).
874*a*. Bloxam, *J. Soc. Chem. Ind.*, **25**, 735 (1906). *b*. Wangerin and Vorländer, *Z. Farb. Textile Chem.*, **1**, 283 (1902); Wagner, *J. prakt. Chem.*, [2] **89**, 383 (1914).
875. Gerland, German pat., 180,097, *Chem. Zentr.*, I, 1371 (1907).
876. Vorländer and Schubart, *Ber.*, **34**, 1860 (1901); see also Tschilikin and Milanowskij, *Chem. Zentr.*, II, 35 (1912).
877. Gaunt, Thomas, and Bloxam, *ibid.*, I, 488 (1908).
878. Grandmougin, *Compt. rend.*, **173**, 586 (1921).
879. Kalle and Co., German pat., 143,141, *Chem. Zentr.*, II, 272 (1903).
880*a*. Schwalbe and Jochheim, *Ber.*, **41**, 3798 (1908). *b*. Nadler, Hoyer, and Bayer, U. S. pat., 2,219,330, *C.A.*, **35**, 1072 (1941).
881. Cohn, "Die Carbazolgruppe," George Thieme, Liepzig, 1919, p. 106.
882. Schultz and Hauenstein, *J. prakt. Chem.*, [2] **76**, 336 (1907).
883. Graebe and Glaser, *Ann.*, **163**, 347 (1872); Bechhold, *Ber.*, **23**, 2144 (1890).
884*a*. Mizuch, *J. Gen. Chem.* (*U.S.S.R.*), **10**, 844 (1940); *C.A.*, **35**, 2509 (1941). *b*. Meister, Lucius, and Brüning, German pat., 268,787, *Frdl.*, **11**, 168.
885. Cassella, German pat., 260,898, *Frdl.*, **11**, 173.
886. Meister, Lucius, and Brüning, German pat., 275,795, *Frdl.*, **12**, 148.

887*a*. Schwalbe and Wolff, *Ber.*, **44**, 236 (1911). *b*. Neelmeier and Goll, German pat., 538,450, *C.A.*, **26**, 1623 (1932).
888. Bayer and Co., German pat., 258,298, *Frdl.*, **11**, 170.
889. Bayer, German pat., 224,952, *Frdl.*, **10**, 146.
890*a*. Bergdolt and Schmelzer, German pat., 603,945, *C.A.*, **29**, 819 (1935); British pat., 417,794, *C.A.*, **29**, 1438 (1935). *b*. Strukov and Smirnov, *J. Applied Chem.* (*U.S.S.R.*), **13**, 1474 (1940); *C.A.*, **35**, 4020 (1941).
891. Meister, Lucius, and Brüning, German pat., 291,023, *Frdl.*, **12**, 148.
892. Wirth, Dortmund, and Schott, German pat., 128,854, *Frdl.*, **6**, 60.
893. Fischer, *Ber.*, **15**, 62 (1882); Fischer and Riemerschmid, *Ber.*, **16**, 1183 (1883); Fischer and Renouf, *Ber.*, **17**, 763 (1884); Leone and Oliveri, *Gazz. chim. ital.*, **15**, 274 (1885); Weidel and Murmann, *Monatsh.*, **16**, 750 (1895); Hantzsch, *Ber.*, **19**, 35 (1886); Meyer, *Monatsh.*, **24**, 203 (1903).
894. Meyer and Ritter, *ibid.*, **35**, 765 (1914).
895. van Gastel and Wibaut, *Rec. trav. chim.*, **53**, 1031 (1934).
896. Wulff, German pat., 541,036, *C.A.*, **26**, 1945 (1932); British pat., 335,817, *C.A.*, 25, 1537 (1931); U. S. pat., 1,880,646, *C.A.*, **27**, 516 (1933); Machek, *Monatsh.*, **72**, 77 (1938).
897*a*. Plazek, *Roczniki Chem.*, **16**, 403 (1936); **17**, 97 (1937); *C.A.*, **31**, 1808, 4669 (1937). *b*. Chichibabin and Tyazhelova, *J. Russ. Phys.-Chem. Soc.*, **50**, 495 (1920); *C.A.*, **18**, 1495 (1924). *c*. Machek, *Monatsh.*, **73**, 180 (1940); *C.A.*, **35**, 4381 (1941).
898*a*. Chichibabin and Vialatout, *Bull. soc. chim.*, **6**, 736 (1939). *b*. Plazek and Marcinkow, *C.A.*, **29**, 2535 (1935).
899. v. Schickh, German pat., 601,896, *C.A.*, **28**, 7267 (1934).
900. Lubavin, *Ann.*, **155**, 313 (1870); Fischer, *Ber.*, **15**, 1979 (1882); **20**, 731 (1887); Riemerschmied, *Ber.*, **16**, 721 (1883); La Coste and Valeur, *Ber.*, **20**, 95 (1887); v. Georgievics, *Monatsh.*, **8**, 577, 639 (1887); Claus, *J. prakt. Chem.*, [2] **37**, 258 (1888); Fulda, *Z. phys. Chem.*, **6**, 490 (1890); Weissgerber, *Ber.*, **47**, 3179 (1914).
901. Bedall and Fischer, *Ber.*, **15**, 684 (1882); Fischer, *Ber.*, **20**, 731 (1887).
902. Orlov and Bogdanov, *J. Applied Chem.* (*U.S.S.R.*), **5**, 803 (1932); *C.A.*, **27**, 724 (1933).
903. La Coste and Valeur, *Ber.*, **19**, 995 (1886); **20**, 98, 3199 (1887).
904. Herzfeld, *Ber.*, **17**, 1550 (1884).
905*a*. Claus and Posselt, *J. prakt. Chem.*, [2] **41**, 33 (1890). *b*. Matsumura, *J. Am. Chem. Soc.*, **49**, 813 (1927).
906. J. D. Riedel-E. de Haën A.-G., German pat., 552,920, *C.A.*, **26**, 5577 (1932).
907. Cybulski, Sucharda, Troszkiewiczówna, and Turska, *Roczniki Chem.*, **14**, 1172 (1934); *C.A.*, **29**, 6235 (1935).
908*a*. Claus and Imhoff, *J. prakt. Chem.*, [2] **57**, 79 (1898). *b*. Rudolph, German pat., 110,175, *Chem. Zentr.*, II, 461 (1900).
909. Kaufmann and Radosevic, *Arch. sci. phys. nat.*, **25**, 518 (1908); *C.A.*, **2**, 2378 (1908).
910*a*. Matsumura, *J. Am. Chem. Soc.*, **57**, 1534 (1935). *b*. Matsumura, *ibid.*, **60**, 593 (1938).
911*a*. Pyman and Ravald, *J. Chem. Soc.*, **117**, 1429 (1920). *b*. Barnes and Pyman, *ibid.*, 2711 (1927).
912. Forsyth, Moore, and Pyman, *ibid.*, **125**, 919 (1924).

913*a*. Quilico and Justoni, *Gazz. chim. ital.*, **70**, 1 (1940). *b*. Ochiai, *J. Pharm. Soc. Japan*, **58**, 1040 (1938); *C.A.*, **33**, 3791 (1939). *c*. Scudi and Buhs, *J. Am. Chem. Soc.*, **63**, 879 (1941).

914. Neri, *Gazz. chim. ital.*, **59**, 384 (1929).

915. Neri, *ibid.*, **61**, 597 (1931).

916. Kitasato and Goto, *Ber.*, **63B**, 2696 (1930); *J. Chem. Soc. Japan*, **52**, 162 (1931).

917. Zahn, *Biochem. Zeit.*, **68**, 467 (1915).

918. Knoll and Co., German pat., 188,054, *Frdl.*, **8**, 1162.

919. Speyer and Becker, *Ber.*, **55B**, 1329 (1922).

920. Freund and Speyer, *Ber.*, **44**, 2339 (1911).

921. Speyer and Koulen, *Ann.*, **438**, 50 (1924); Speyer and Wieters, *Ber.*, **54B**, 2976 (1921).

922. Giemsa and Halberkann, *Ber.*, **53B**, 732 (1920); Giemsa and Bonath, *Ber.*, **58B**, 87 (1925); Giemsa and Oesterlin, *Ber.*, **64B**, 57 (1931).

B. SULFONIC ACIDS FROM SULFITE REACTIONS*

There are a number of interesting and in some instances valuable methods for obtaining sulfonic acids which depend upon the reactions of various types of compounds with sulfurous acid or sulfites. Since a sulfonic acid may be considered to be a derivative of sulfuric acid all of these reactions involve oxidation of the sulfur and it is convenient to group them together.

Reaction of Sulfites with Phenols. On the assumption that phenolic compounds might act in their keto form Fuchs and Elsner[1] heated hydroquinone, resorcinol,[2] pyrogallol, hydroxyhydroquinone,[3] and phloroglucinol[4] with sodium bisulfite solution ranging over periods up to two weeks. Reaction occurred with each compound but only for resorcinol was an aromatic sulfonic acid obtained, and here only when the primary addition product was decomposed by successive treatments with base and acid. The product was later[5] shown to be phenol-*m*-sulfonic acid. The mechanism by which this is formed is still uncertain. Phenol itself does not react with sodium bisulfite.[2c]

Reaction of Sulfites with Quinones. Treatment of benzoquinone with sulfurous acid[6] gives as the chief products hydroquinone and sulfuric acid, but there is also formed about 20% of hydroquinonesulfonic acid. A quantitative study of this reaction[7] and that of some substituted quinones with sulfurous acid to which varying amounts of sodium hydroxide had been added showed that the greatest amount of sulfonic acid formation occurred when a mixture of sodium sulfite and sodium bisulfite was present. Some of Dodgson's[7] results are presented in Table XXVIII.

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* References for this section on p. 368.

TABLE XXVIII

Reaction of Quinones with Sulfite

Quinone		Moles NaOH per Mole of SO_2			
		0.0	1.0	1.5	2.5
p-Benzoquinone	reduction, %	77	78	3.2	3.5
	sulfonation, %	22	20	80	40
p-Toluquinone	reduction, %	75	..	6.3	3.0
	sulfonation, %	24	..	58	44
p-Xyloquinone	reduction, %	83	..	51	3.0
	sulfonation, %	17	..	44	52
2,3-Dimethyl-*p*-benzoquinone	reduction, %	77	..	48	6.5
	sulfonation, %	23	..	48	51
Chloro-*p*-benzoquinone	reduction, %	86	..	9.4	3.8
	sulfonation, %	13	..	81	60

When two or more halogens are present in the quinone nucleus the reaction is complicated by a removal of the halogen and formation of disulfonic acids. Quantitative results are again available for two dichloroquinones.[7] Here sulfonation, %, refers to one sulfonic acid group so that values above 100 indicate disulfonation. With tetrachloroquinone[8] the reaction with sulfurous acid occurs as follows.

TABLE XXIX

Dichloroquinones and Sulfite

Compound		Moles NaOH per Mole of SO_2			
		0.0	1.0	1.5	2.0
2,5-Dichloro-1,4-benzoquinone	reduction, %	76	45	24	20
	sulfonation, %	34	98	164	189
	one Cl removed, %	10.6	44	104	127
2,6-Dichloro-1,4-benzoquinone	reduction, %	83	60	15	11.4
	sulfonation, %	18	58	172	172
	one Cl removed, %	0.4	18	93	122

$$C_6Cl_4O_2 + H_2SO_3 + H_2O \rightarrow C_6Cl_3(OH)_2SO_3H + H_2SO_4 + HCl$$

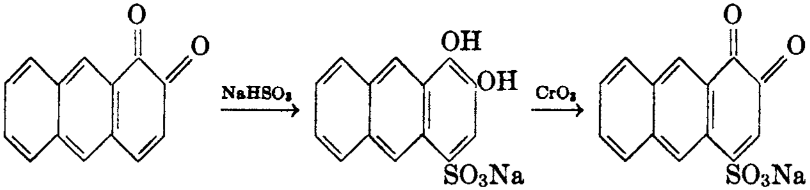
The barium salt of each sulfonic acid formed in the above reactions was isolated and described.

Shaking a benzene solution of tetrabromo-*o*-benzoquinone with potassium sulfite solution[9] at room temperature yields a dibromocatecholdisulfonate. At a temperature above 50° a compound, $C_6H_3O_3(SO_3K)_5$, of unknown structure resulted. Some unknown factor controlled the formation of this, however, and part of the time it could not be prepared.

The formation of hydroquinonemono and catecholdisulfonates when the corresponding phenols are treated with an alkali sulfite in the presence of lead dioxide, cupric hydroxide, or silver bromide[10a] undoubtedly proceeds through the step of quinone formation and hence belongs in this discussion. After two sulfonic acid groups are introduced oxidation to a quinone no longer occurs with mild oxidizing agents and the compound is therefore not a photographic developer.

Heating a mixture of 2-naphthol and sodium sulfite with copper oxide preferably in alkaline solution gives sodium 2-naphthol-1-sulfonate and naphthol oxidation products.[10b] The yield of sulfonate is much improved by the use of manganese dioxide in neutral solution. The sulfonation has also been effected with 2-hydroxy-3-naphthoic acid, 2-naphthol-6-sulfonic acid,[10d] the 4- and 7-sulfonic acids, and the 3,6-disulfonic acid,[10e] but no change occurs with compounds already having a sulfo group in the 1-position.[10f] The mechanism of the reaction is not yet clear, although it probably involves the action of sulfite ion with an oxidation product of the naphthol.

The reaction of sodium bisulfite upon 1,2-anthraquinone followed by chromic acid oxidation yields the 4-sulfonic acid.[10c]



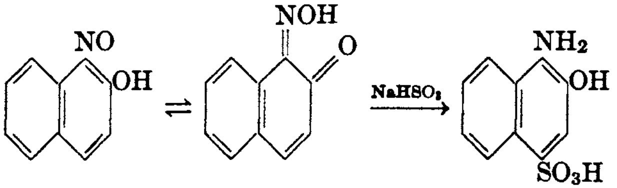
p-Phenylenediamine may also be sulfonated by the action of a sulfite with silver bromide but here lead dioxide did not give good results.[11a] Potassium dichromate [11b] in dilute acetic acid solution has also been used as an oxidizing agent in this reaction.

The sulfonic acids derived from strychnine and brucine have been carefully investigated over a period of nearly thirty years. They are obtained by treating the alkaloid with sulfurous acid and manganese dioxide.[12] In this manner brucine and strychnine each yield four isomeric monosulfonic acids. These are believed to be for each alkaloid the two stereoisomeric forms of two structural isomers. Substitution probably occurs in a benzene ring. Degradation reactions of these acids have been extensively investigated.

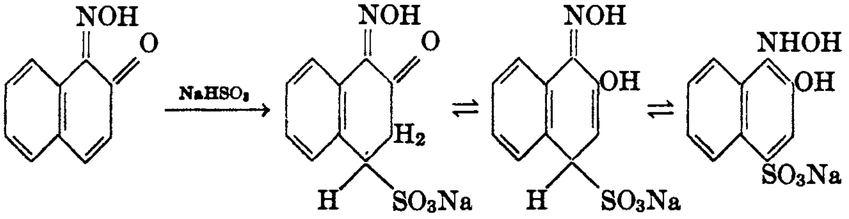
Lignosulfonic Acids. In connection with the results obtained by the action of sulfites upon phenols and quinones there should be mentioned the sulfonic acids formed in the removal of lignin from wood in the sulfite process for making paper. Much labor has been expended in attempts to elucidate the structure of these acids without anything approaching complete success having been attained.[13] There are two views extant as to the nature of the lignosulfonic acids. One is that the bisulfite reacts with phenolic compounds in their tautomeric keto forms[14] much as it does with resorcinol. The other and more probable is that the sulfite has added to a double bond,[15] this probably being conjugated with a carbonyl group in a side chain of the cinnamic aldehyde type.

Recent investigators[16a] believe that a complex mixture of sulfonic acids results in the sulfite process although others[15,16b] claimed the isolation of pure products. The sulfonic acid (or acids) precipitated by β-naphthylamine is referred to as α-ligninsulfonic acid and that (or those) remaining in solution as the β-compound. According to Klason[17] the least sulfite ever found in combination gives a compound with the formula $C_{30}H_{30}O_9 \cdot H_2SO_3$ while complete reaction yields $C_{10}H_{10}O_3H_2SO_3$. The ordinary α-lignosulfonic acid has the approximate formula $C_{40}H_{42}O_6(SO_3H)_2$.[18] The products obtained under various conditions have been described by Hibbert and co-workers.[16a]

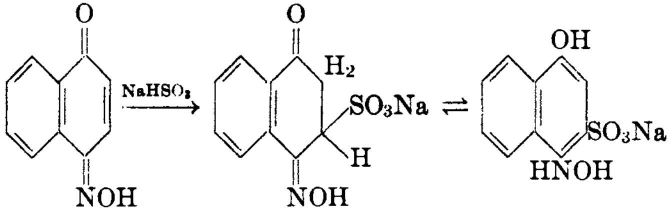
Reaction of Azo and Nitroso Compounds with Bisulfites. Certain nitrogen derivatives of phenols and naphthols which may exist in the form of the tautomeric quinone derivatives are converted into sulfonic acids through treatment with sodium bisulfite. Thus 1-nitroso-2-naphthol gives rise to the sulfonic acid[19] shown in the equation.



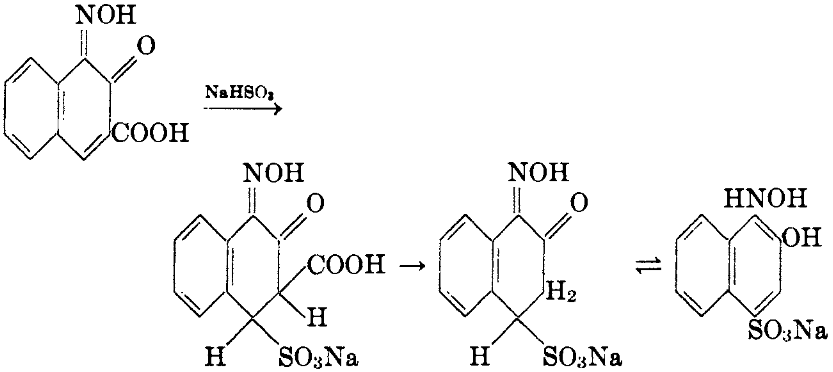
The mechanism of this reaction has more recently received considerable attention. The nitrosonaphthol, its 6-sulfonic acid, and the O-methyl ether of the oxime all yield definite addition products with sodium bisulfite.[20] This is also true for 4-nitroso-1-naphthol but not for the 2-nitroso compound. The bisulfite addition product of 1-nitroso-2-naphthol upon treatment with any one of a number of reducing agents[21] is converted into the sulfonic acid already mentioned. The most satisfactory explanation of this and other reactions of this addition product is to assume that it corresponds to one or more of the tautomeric forms indicated.



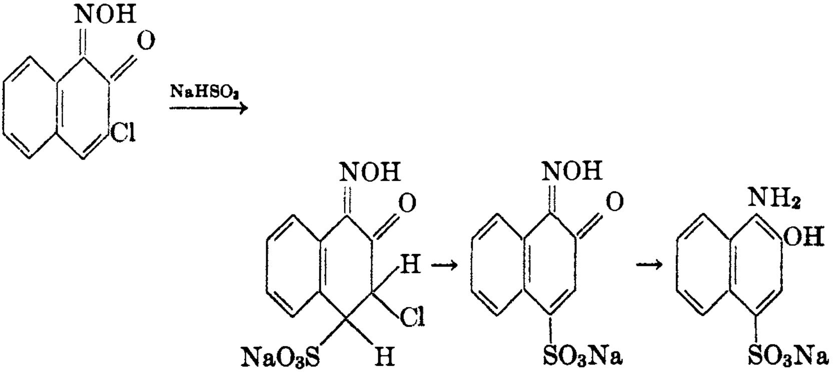
The last of these and possibly the others might be expected to reduce to the aminosulfonic acid actually formed. The reaction of 4-nitroso-1-naphthol can be formulated similarly.



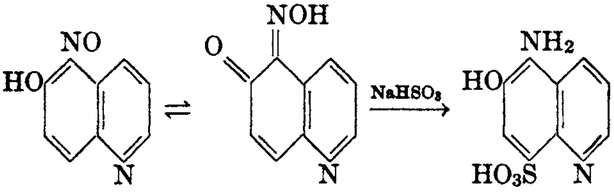
This explanation of the step preceding the reduction agrees very well with the observation that 1-nitroso-2-hydroxy-3-naphthoic acid loses carbon dioxide during reduction with sodium bisulfite.[22]



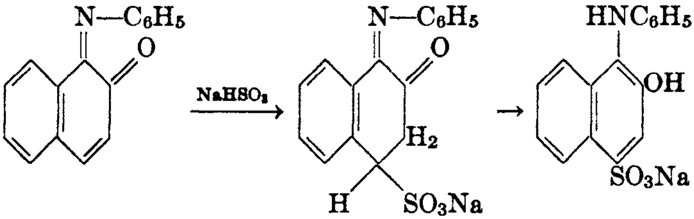
As might be expected, if the acid is converted into an anilide or ester, elimination of the group does not occur.[23a] On the other hand the chlorine atom in 3-chloro-1-nitroso-2-naphthol is lost [19a] during treatment with bisulfite.



5-Nitroso-6-hydroxyquinoline reacts just as its naphthol analog does toward sodium bisulfite.[23b]

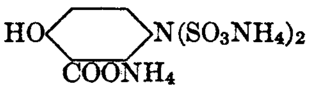


The conversion of 1-phenylimino-2-naphthoquinone into a sulfonic acid by the action of sodium bisulfite [24] is analogous to the foregoing.

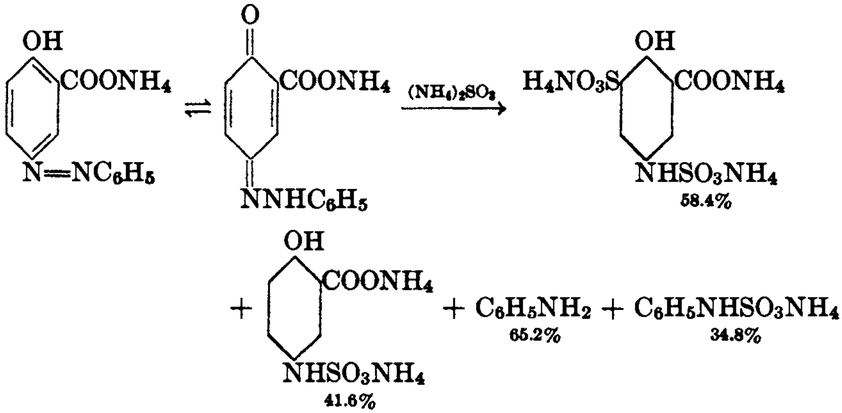


The same mechanism may again be applied to the reactions of hydroxyazo dyes,[25] including those derived from 5-hydroxyquinoline.[23b] These reactions are closely related to Bucherer's [26] method for replacing a hydroxy by an amino group through the action of ammonium sulfite, and the reverse reaction of converting the amine to the naphthol with sodium bisulfite, since both apparently involve the reaction of the keto forms of the naphthols.

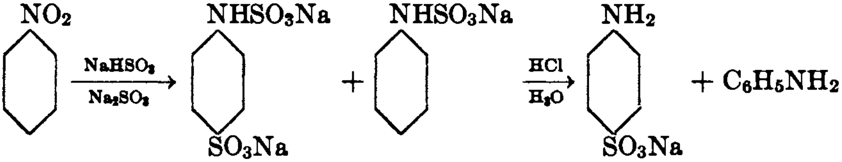
In the cleavage of certain *p*-hydroxybenzeneazo dyes with ammonium sulfite Engel believed [27] that one of the reaction products was an N-disulfonate with the accompanying formula. In the light of the



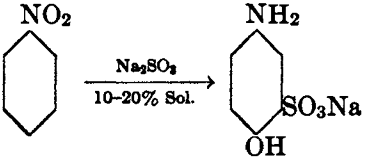
behavior of the naphthol compounds this may actually be the isomeric sulfonic acid with one sulfo group attached to the nucleus. This is supported by the observation that a sulfonic acid resulted upon hydrolysis of the supposed N-disulfonate with hydrochloric acid. Since N-sulfonic acids do not in general undergo rearrangements under hydrolytic conditions,[28] N-disulfonic acids would hardly be expected to. The cleavage reaction may then be written as follows, the percentages of the various reaction products as reported by Engel [27] being included.



Reaction of Nitro Compounds with Sulfites; the Piria Reaction. Refluxing aromatic nitro compounds with a metal sulfite[29] results in the production of an arylaminosulfonic (arylsulfamic) acid or its sulfonation product or both. Boiling this mixture with dilute acid yields the amine and aminesulfonic acid.

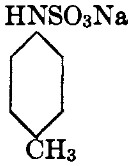


In some cases, notably in the naphthalene series, disulfonation may result, and in at least one reaction,[30] that of nitrobenzene with sodium sulfite, an aminophenolsulfonic acid results in 50% yield under one set of reaction conditions.



These reduction and sulfonation reactions, followed by acid hydrolysis, have been referred to by Hunter and Sprung[31] as the Piria reaction. Most of the interest in this complicated transformation has been from the standpoint of possible application in the preparation of dye intermediates.[32] The mechanism of the nuclear sulfonation is not known. It is evident that this occurs before the hydrolysis with acid, however, since the arylaminosulfonic acids do not rearrange to nuclear sulfonic acids under this treatment. The fact that nitroso and azo compounds give sulfonation products, as has been noted in the preceding section, may mean that all these reactions have one or more steps in common.

Heating nitrobenzene with ammonium sulfite solution[29d] gives a small yield of ammonium phenylaminosulfonate. A larger amount of the sodium salt of this and other arylaminosulfonic acids results by heating the nitro compound with three moles of sodium bisulfite and one of sodium sulfite[33a] in dilute aqueous solution. In this procedure the ratio of arylaminosulfonic acid to sulfoarylaminosulfonic acid varies greatly with the substituent present in the aromatic ring, and also varies to some extent for any one nitro compound, depending upon the alkalinity of the sulfite solution.[33b] Thus with *p*-nitrotoluene, I is a minor product, II being formed in larger amount, while for nitrobenzene 60% of the reaction product is III and the remainder IV.



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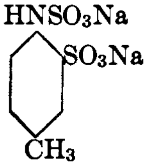
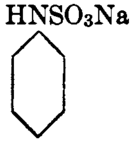


II



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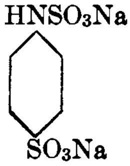
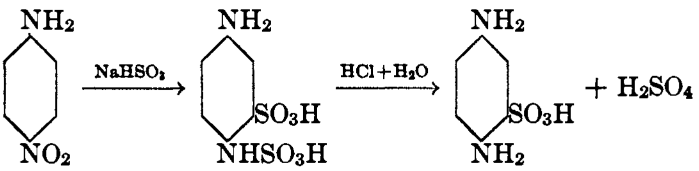


IV

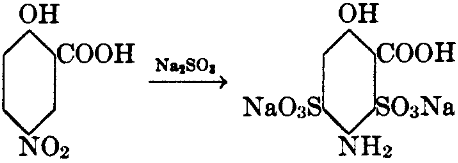
A mixture of the two products is similarly obtained from *o*- and *p*-chloronitrobenzene, *o*-nitrotoluene, *p*-nitrophenetole, *o*-nitroanisole, and *p*-nitrobenzoic acid. On the other hand *p*-acetaminonitrobenzene[34] and its methyl and methoxy derivatives give quantitatively the N-sulfonic acids which are not sulfonated in the nucleus. *p*-Dimethylaminonitrobenzene apparently reacts similarly, but the products were found to be too soluble to isolate satisfactorily. The N-benzylnitranilines do not react with sodium bisulfite. *m*-Nitraniline and the *para* isomer are reported to give the products shown.



o-Nitraniline gives only the N-sulfonic acid.

The behavior of *m*-dinitrobenzene is interesting. At a low temperature with sodium bisulfite solution the product is *m*-nitrophenylaminosulfonic acid (as the sodium salt), whereas if the reaction solution is boiled and sodium sulfite is added both nitro groups are reduced to give sodium *m*-phenylenedi-(aminosulfonate), $C_6H_4(NHSO_3Na)_2$.

Using sodium sulfite alone, 3-nitro-4-sulfophenylaminosulfonic acid has been identified [35a] as one of the reaction products. The reduction of 5-nitrosalicylic acid is unusual in that a disulfonic acid results from the action of a large excess of sodium sulfite.[35b] Attempts to get a pure monosulfonic acid were unsuccessful, a mixture containing dihydroxy and disulfo compounds resulting.



The first application of the Piria reaction in the naphthalene series was by the discoverer of this method of sulfonation and reduction.[29a] α-Nitronaphthalene with ammonium sulfite gives ammonium naphthionate and α-naphthylaminosulfonic acid. Using sodium bisulfite an 80% yield of 1-naphthylamine-2,4-disulfonic acid has been reported.[36]

Refluxing 20 g. of 1,8-dinitronaphthalene with 267 g. of 30% sodium bisulfite until it practically all dissolves (about 17 hours) produces a mixture of sulfonic acids.[37] Among these are 1,8-diaminonaphthalene-2,4,5-trisulfonic acid and the sulfite addition product of 1-amino-8-naphthol-2,4,5-trisulfonic acid. With sodium bisulfite to which ammonia has been added there result chiefly 1-aminonaphthalene-4,7-disulfonic acid and the sulfite of 1-amino-8-naphthol-4,5-disulfonic acid.

Heating 1-nitrobenzanthrone with sodium bisulfite solution gives the 1-amino-2-sulfonic acid.[38]

In an effort to standardize the conditions for the Piria reaction Hunter and Sprung [31] investigated the effect of a given set of reaction conditions upon a number of nitro compounds. These conditions consisted of the treatment of one mole of nitro compound with a 75% excess of sodium bisulfite over the three moles necessary to produce complete reduction. Enough 5 *N* alkali was added to a 2.6 *M* solution of the bisulfite to neutralize one-fourth of it. The nitro compound was refluxed with the stirred solution until the mixture became homogeneous. This was then evaporated to one-half its volume and 250 ml. of 12 *N* hydrochloric acid added. Hydrolysis was usually complete after 2 hours or less of boiling the acid solution. The results obtained are summarized in Table XXX.

Reaction of Sulfites with Halo and Nitro Groups; Replacement. The reaction of an alkyl halide with a sulfite is one of the best methods for preparing aliphatic sulfonic acids but in the aromatic series

TABLE XXX

ACTION OF SULFITE ON NITRO COMPOUNDS

Nitro Compound	Reduction Time, Hours	Amine Isolated, %	Arylaminesulfonic Acid(s), %
$C_6H_5NO_2$	1.25	26	Sulfanilic, 27
1-$C_{10}H_7NO_2$	5	2	Naphthionic, 25; 1-naphthylamine-2,4-disulfonic, 66
2-$CH_3C_6H_4NO_2$	12	40(+12% of $ArNHSO_3Na$)	4-Sulfonic, 34
4-$CH_3C_6H_4NO_2$	5	72	2-Sulfonic, 11
2,5-$(CH_3)_2C_6H_3NO_2$	17[1]	60	4-Sulfonic, 16
4-NO_2-C_6H_4COOH	4.5	21	3-Sulfonic, 61
4-NO_2-C_6H_4OH	11	..	3-Sulfonic, 14

[1] Three times normal amount of water used. Ordinarily 1250 ml. of water was added to the reduction mixture before refluxing.

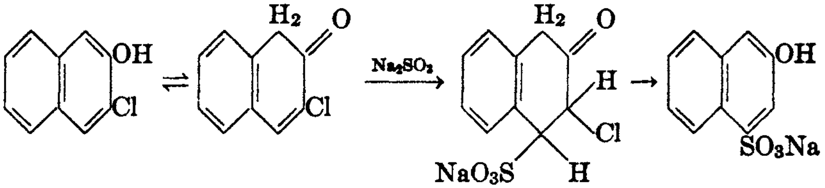
this procedure is of little value because of the relative inertness of halogen when attached to an aromatic ring. However, in a few compounds the reactivity of halogen and occasionally the nitro group is sufficient for conversion to the sulfonic acid to occur with ease; this depends upon the presence of nitro or carbonyl groups in the *ortho* or *para* position.

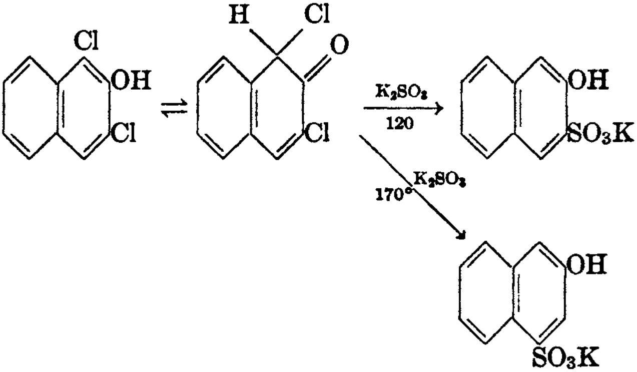
Bromobenzene reacts with aqueous sodium sulfite in the presence of copper sulfate[39] if the reaction mixture is heated to 180–200° in a sealed tube for 7 hours. *p*-Bromotoluene behaves analogously. Sodium *o*-bromobenzenesulfonate reacts at 120–130° while the *meta* isomer requires a temperature of 170–180°. With the *o*- and *m*-bromocinnamic acids[40] addition to the double bond as well as replacement of the bromine occurs. The sulfo group in the side chain may be removed by alkali, however, without affecting the nuclear sulfonic acid.

The chlorine of *o*-chlorobenzaldehyde may be replaced by a sulfo group without a copper catalyst if the reaction is carried out at high temperatures and pressures.[41a] 4-Chloro-2′-carboxybenzophenone reacts with sodium sulfite solution in the presence of cupric ions[41b] at temperatures above 100°. The 3,4-dichloro compound behaves similarly.[41c]

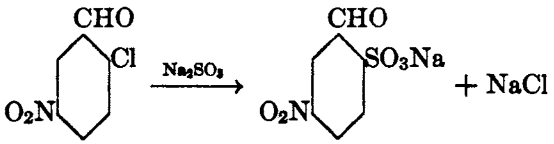
When 2,4,6-trichlorophenol is heated with a saturated aqueous solution[42a] of potassium sulfite under pressure at 170° first one and then the other of the chlorines *ortho* to hydroxyl are replaced by a sulfonate group. Some of the halonaphthols show anomalous reactions with sulfites.[42b] Thus 3-chloro-2-naphthol yields the 4-sulfo-2-naphthol and 1,3-dichloro-2-naphthol is converted into 2-naphthol-3-sulfonic acid.

Quite possibly an intermediate step in these reactions involves the keto forms of the naphthols, but it is difficult to utilize this idea in the reaction of the dichloro compound.

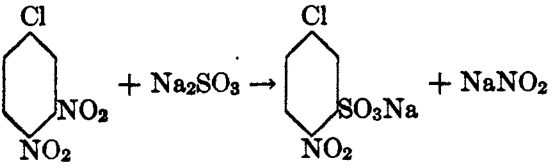




It has already been noted that *ortho* and *para* chloronitrobenzenes are reduced to chlorophenylaminosulfonates by the action of sulfites. Certain other halonitro compounds, however, react to give good yields of sulfonic acids by replacement reactions. Thus 2-chloro-5-nitrobenzaldehyde[43] reacts rapidly with boiling aqueous sodium sulfite.



2,4-Dinitrochlorobenzene reacts with sodium sulfite in aqueous-alcohol solution[44] to give sodium 2,4-dinitrobenzenesulfonate. When 3,4-dinitrochlorobenzene is treated in an analogous manner[45] a nitro group is replaced.



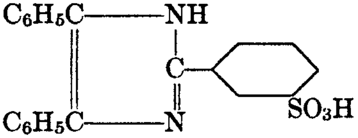
Refluxing sodium 3-nitro-4-chlorobenzenesulfonate with aqueous sodium sulfite[46] replaces the halogen with a sulfonate group. Picryl chloride reacts with alcoholic sodium bisulfite[43b] to yield the trinitrosulfonic acid.

A few sulfonic acids of polycyclic compounds have also been obtained by replacement reactions. Heating 9,10-dichloroanthracene in an autoclave with sodium sulfite[47a] produces the corresponding disulfonic acid. The trisulfonate has been obtained[47c] from 9,10-dichloroanthracene-2-sulfonic acid. The bromine of 10-bromophenanthrene reacts with sodium sulfite solution with great difficulty, possibly because of the immiscibility of the reactants, while 10-bromophenanthrene-3-sulfonate is converted into the disulfonate[47b] at 260–270°.

9-Nitroanthracene reacts readily with sodium sulfite solution[48] to produce the corresponding sulfonic acid. Remarkably enough, 1-nitroanthraquinone may be converted into the sulfonic acid by refluxing with 9% sodium sulfite solution for two days.[49a] Likewise the 1-nitro- and the 1,5- and 1,8-dinitro-2-methylanthraquinones react with sodium bisulfite in the presence of copper with replacement of the nitro groups.[49b] 2,3-Dichloro-1,4-diaminoanthraquinone has been converted into mono[50] and disulfonic[51] acids by reaction with sulfites.

Several halogenated heterocyclic compounds have been studied. 2-Chlorobenzoxazole or benzothiazole when treated with sodium sulfite gives the corresponding sulfonate.[52a] Treatment of 2,3,5-trichloropyridine or 3,4,5-trichloropyridine with sodium bisulfite[52b] gives a dichloropyridinesulfonic acid, the chlorines in the 2- or 4-position reacting readily. Quinoline-2-sulfonic acid and its 3-methyl derivative are also obtainable from the corresponding chloro compounds and sodium sulfite.[52c] Acridine reacts with sodium bisulfite to form the sodium salt of 9,10-dihydroacridine-9-sulfonic acid.[52d] When sulfur dioxide and acridine hydrochloride react the red acridine salt of the sulfonic acid precipitates.

Reaction of Sulfites with Diazonium Compounds. A few sulfonic acids have been prepared directly from diazonium salts. Thus benzenediazonium sulfate in the presence of cuprous hydroxide and a sulfite[53] is transformed into benzenesulfonic acid. The three toluenesulfonic acids have been obtained by the action of sulfurous acid upon the diazonium chlorides.[54] *m*-Diazobenzoic acid with sulfur dioxide in alcohol gives *m*-sulfobenzoic acid.[55] A complex imidazole derivative having the accompanying formula has been prepared similarly.[56a]



The preparation of sodium 2-naphthol-1,4-disulfonate and other related compounds from aminonaphtholsulfonic acids has been described in the patent literature.[56b]

C. SULFONIC ACIDS BY OXIDATION REACTIONS*

Vigorous oxidation of any compound in which the sulfur attached to an aromatic ring is present as a thiol, disulfide, or sulfinic acid leads to the formation of a sulfonic acid or sulfonyl halide, depending upon the oxidizing agent. Sulfonic acids are also formed in some instances from sulfides, sulfoxides, and sulfones if one of the organic groups is aliphatic. Oxidation methods are frequently of value in the preparation of sulfonic acids that cannot be obtained by direct sulfonation, and in the proof of structure.

Nitric Acid Oxidation. Nitric acid is convenient to use in the formation of sulfonic acids by an oxidation because the nature of the by-products renders isolation of the reaction product simple. Thiophenol, the corresponding disulfide,[57] and benzenesulfinic acid[58] have been converted into benzenesulfonic acid by this reagent. *p*-Toluenesulfinic acid undergoes both oxidation and nitration[59] when treated with concentrated nitric acid. 2,4-Dinitrothiophenol gives the dinitrosulfonic acid.[60] A number of substituted phenyl disulfides including bis-(2-nitrophenyl),[61,62] bis-(4-nitrophenyl),[61,62] bis-(2,4-dinitrophenyl),[60] bis-(2-nitro-4-chlorophenyl),[62] the corresponding bromo compound, and bis-(2-nitro-5-chlorophenyl) disulfides yield sulfonic acids when treated with fuming nitric acid. Using ordinary nitric acid sulfonic acids have also been obtained from the above-mentioned bis-(2,4-dinitrophenyl) disulfide[63] and the bis-(2-nitro-4,6-dichloro) and dibromo compounds.[64] *p*-Nitrophenylsulfur chloride with nitric acid in glacial acetic acid[65a] yields a mixture containing *p*-nitrobenzenesulfonic acid, the corresponding sulfonyl chloride, and the thiosulfonate, $O_2NC_6H_4SO_2SC_6H_4NO_2$.

When bis-(2-nitrophenyl) disulfide is oxidized by a mixture of nitric and hydrochloric acids[65b] the product is 2-nitrobenzenesulfonyl chloride. This method was chosen as the most suitable for preparing this compound and the corresponding acid after a careful study of several other possibilities. Bis-(2-methyl-4-anthraquinonyl) disulfide has been converted to the sulfonic acid by nitric acid oxidation.[65c]

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* References for this section on p. 368.

It is not necessary to hydrolyze the xanthate obtained by the action of potassium ethyl xanthate upon a diazonium compound to the corresponding thiophenol before subjecting the compound to oxidation. Thus the ethyl xanthates obtained from orthanilic acid [66a] and 3,5-dinitroaniline [66b] have been oxidized directly to the sulfonic acids by the use of nitric acid. This obviously requires a great deal more oxidizing agent, however, than when the thiophenol is used.

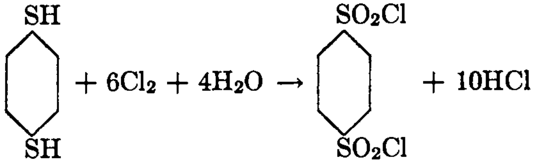
A number of sulfonic acids derived from heterocyclic compounds have been prepared by nitric acid oxidation of the thiols including 4-thiolpyridine,[67a] 2-thiolpyridine-3-carboxylic acid,[67b] 3,5-dichloro-2- and 4-thiolpyridine,[67c] and 4-thiolquinoline.[67d]

Permanganate Oxidation. The reagent most frequently used in the preparation of sulfonic acids by oxidation is potassium permanganate in alkaline solution. Thus *m*-thiocresol,[68] 2-sulfo-4-methylthiophenol,[69] 2-methyl-4-sulfothiophenol,[69] and 2,4-dimethyl-5-sulfothiophenol [70a] are all easily converted into alkali sulfonates by this procedure. The preparation of benzene-o-disulfonic acid has been studied in considerable detail.[70b] Oxidation of the *o*-thiolbenzenesulfonic acid with potassium permanganate gave the most satisfactory results. In the naphthalene series the same reaction has been used to prepare the 1,2-, 1,4-, 1,7-, and 1,8-disulfonic acids,[71] compounds not obtainable by direct sulfonation (except traces of the 1,7-compound), through oxidation of the sulfonaphthalenethiols. Alternatively the disulfides may be used in these last reactions.[72] A large number of naphthalenetrisulfonic acids [71,72] and the 2,3,6,8- and 1,3,6,8-tetrasulfonic acids [72] have been similarly obtained from sulfonated naphthalenethiols.

The 3,5- and 2,3-dimethylbenzenesulfinic acids,[73] tetralin-1-sulfinic acid,[74a] the 2- and 4-methoxy and ethoxybenzenesulfinic acids,[74b] 2-methoxy-5-methylbenzenesulfinic acid,[75] 2- and 4-sulfonaphthalene-1-sulfinic acids,[74b] 4,8-disulfonaphthalene-1-sulfinic acid,[74b] and the corresponding 2-sulfinic acid have all been oxidized to the sulfonates by permanganate in alkaline solution.

There may be mentioned a number of miscellaneous compounds that also give sulfonic acids or their salts as their final oxidation products. These are trithiophenoxymethane,[76] $(C_6H_5S)_3CH$, phenylsulfonylacetone,[77] 2-phenylsulfonyl-1-propanol,[78] 1,2-di-(phenylsulfonyl)-ethane [79] and other similar disulfones. Phenyl benzenethiosulfonate [80] gives two moles of benzenesulfonic acid.

Oxidation with Miscellaneous Reagents. When chlorine or bromine is used as the oxidizing agent in neutral or acid solution the final product is a sulfonyl halide. Thus *p*-thiocresol with bromine in acetic acid[81] probably containing some water is converted into the sulfonyl bromide. Chlorine and bromine behave similarly toward dithiohydroquinone.[81]



This same disulfonyl chloride results from the action of chlorine upon the iodine addition product of the dithiohydroquinone dimethyl sulfide.[81] This reaction was also applied to the 2,5-dibromo derivative of the above compound. What happens to the methyl groups in these reactions is not clear. The same reaction has been used to obtain the sulfonyl chloride from 2-nitro-4-methylphenyl methyl sulfide.[82] The formation of benzenesulfonyl chloride from the electrolysis of an acetic acid solution of phenyl ethyl sulfide containing some hydrogen chloride is probably a chlorine oxidation.[83]

A number of disulfides have been oxidized by chlorine to the sulfonyl chlorides; these include bis-(2-nitro-4-methylphenyl),[84] bis-(2-bromo-4-methyl), and bis-(3-bromo-4-methylphenyl) disulfide.[84]

$$(CH_3C_6H_3BrS)_2 + 5Cl_2 + 4H_2O \rightarrow 2CH_3C_6H_3BrSO_2Cl + 8HCl$$

Toluene-*o*-sulfinic acid or the sodium salt with chlorine in aqueous solution yields the sulfonyl chloride.[85] The *para* isomer has been similarly converted into both the chloride and bromide.[86]

Oxidation of carbazole-3-thiol with hydrogen peroxide yields the sulfonic acid. Oxidation of the thiol derivatives of benzoxazole and benzothiazole with sodium hypochlorite or hydrogen peroxide yields the corresponding sulfonic acids.[87b] 4-Thiol-2′-carboxylbenzophenone has also been oxidized by an alkali hypochlorite.[88] 2-Thiolimidazole at −5° with hydrogen peroxide[89] gives a 46% yield of the sulfonic acid. In one instance, that of 3,4-dimethylbenzenesulfinic acid, barium peroxide[90] was used as the oxidizing agent. Sulfinic acids oxidize in contact with the air, but apparently no use has been made of this reaction as a method for preparing sulfonic acids. Disproportionation of a sulfinic acid to a sulfonic acid and a thiosulfonate occurs under a variety of conditions.[91]

$$CH_3C_6H_4SO_2H + NH_3 \xrightarrow[\text{hot}]{C_6H_6} CH_3C_6H_4SO_3NH_4 + CH_3C_6H_4SO_2SC_6H_4CH_3$$

Bis-(2-methoxyphenyl) disulfide oxidizes to the sulfonic acid when treated with chromic acid in acetic acid solution.[92]

REFERENCES FOR B. SULFONIC ACIDS FROM SULFITE REACTIONS AND C. SULFONIC ACIDS BY OXIDATION REACTIONS

1. Fuchs and Elsner, *Ber.*, **52B**, 2281 (1919).

2a. Fuchs and Elsner, *Ber.*, **53B**, 886 (1920). *b.* Bucherer, *Ber.*, **53B**, 1457 (1920). *c.* Bucherer and Hoffman, *J. prakt. Chem.*, [2] **121**, 113 (1929).

3. Fuchs and Elsner, *Ber.*, **57B**, 1225 (1924).

4. Fuchs, *Ber.*, **54B**, 245 (1921).

5. Lauer and Langkammerer, *J. Am. Chem. Soc.*, **56**, 1625 (1934).

6. Dodgson, *J. Chem. Soc.*, **105**, 2135 (1914); Pinnow, *J. prakt. Chem.*, [2] **89**, 536 (1914).

7. Dodgson, *J. Chem. Soc.*, 2498 (1930).

8. Greiff, *Z. Chem.*. 341 (1863).

9. Jackson and Beggs, *J. Am. Chem. Soc.*, **38**, 676 (1916).

10a. Seyewetz and Szymson, *Bull. soc. chim.*, **53**, 1260 (1933); Garreau, *Ann. chim.*, **10**, 485 (1938). *b.* Bogdanov and Ivanova, *J. Gen. Chem.* (*U.S.S.R.*). **7**, 2884 (1937); *C.A.*, **32**, 5393 (1938). *c.* Fieser, *J. Am. Chem. Soc.*, **50**, 465 (1928). *d.* Bogdanov and Ivanova, *J. Gen. Chem.* (*U.S.S.R.*), **8**, 1071 (1938). *e.* Bogdanov, *ibid.*, 9, 1145 (1939). *f.* Bogdanov, *ibid.*, 9, 1846 (1939); *C.A.*, **34**, 4067 (1940).

11a. Seyewetz, *C.A.*, **29**, 6585 (1935). *b.* Vanino, "Handbuch der prapärativen Chemie," Vol. II, Enke, Stuttgart, 1914, p. 615.

12. Leuchs and Schneider, *Ber.*, **41**, 4393 (1908); Leuchs and Geiger, *Ber.*, **42**, 3067 (1909); Leuchs and Anderson, *Ber.*, **44**, 3049 (1911); Leuchs and Wutke, *Ber.*, **45**, 3686 (1912); Leuchs and Boll, *Ber.*, **43**, 2362 (1910); Leuchs, Schlempp, and Baur, *Ber.*, **65B**, 1121 (1932); Leuchs, Schlempp, and Dornow, *Ber.*, **66B**, 743 (1933).

13. The chemistry of the sulfite process cannot be discussed in detail here. For such a discussion and complete references see Hawley and Wise, "The Chemistry of Wood," the Chemical Catalog Co., New York, 1926, pp. 77-87; Schorger, "Chemistry of Cellulose and Wood," McGraw-Hill Book Company, New York, 1926, pp. 72 and 387; Hess, "Die Chemie der Cellulose und ihrer Begleiter," Akademische Verlagsgesellschaft m. b. H. Leipzig, 1928, p. 139. Some contributions in the journal literature are: Freudenberg and Sohns, *Ber.*, **66B**, 262 (1933); Klason, *C.A.*, **26**, 6132 (1932); Hägglund, Ekwall, and Hostomsky, *ibid.*, **26**, 6133 (1932); Hägglund and Johansson, *Cellulosechemie*, **13**, 139 (1932); Hägglund, *Zellstoff und Papier*, **13**, 261 (1933); *C.A.*, **27**, 3815 (1933); *C.A.*, **24**, 5152 (1930); Klason, *C.A.*, **25**, 1077 (1931); Kruger, *Zellstoff und Papier*, **14**, 89 (1934); Hägglund and Hedlund, *C.A.*, **27**, 1949 (1933); Hägglund, Johnson, and Trygg, *Cellulosechemie*, **11**, 30 (1930); Hägglund and Carlsson, *Biochem. Z.*, **257**, 467 (1933); Freudenberg, Sohns, and Janson, *Ann.*, **518**, 62 (1935); King,

Brauns, and Hibbert, *Can. J. Research*, **13**, 88 (1935); Buckland, Tomlinson, and Hibbert, *ibid.*, **B16**, 54 (1938); Leger and Hibbert, *J. Am. Chem. Soc.*, **60**, 565 (1938). A recent book is, "The Chemistry of Pulp and Paper Making" by Suter-Meister, Third Edition, John Wiley & Sons, New York, 1941.

14. Hönig and Fuchs, *Ber.*, **60B**, 782 (1927).
15. Klason, *Ber.*, **63B**, 706 (1920); Sankey and Hibbert, *Can. J. Research.*, **5**, 1 (1932); Klason, *C.A.*, **24**, 3358 (1930).
16*a*. Tomlinson and Hibbert, *J. Am. Chem. Soc.*, **58**, 340, 345 (1936). *b*. Samec and Ribaric, *Kolloidchem.*, **24**, 157 (1927).
17. Klason, *Ber.*, **58B**, 1761 (1925).
18. Klason, *Ber.*, **58B**, 375 (1925); Dorée and Barton-Wright, *J. Soc. Chem. Ind.*, **48**, 9T (1929).
19. Schmidt, *J. prakt. Chem.*, [2] **44**, 522 (1891); Böniger, *Ber.*, **27**, 23 (1894); Friedländer and Reinhardt, *Ber.*, **27**, 241 (1894); Fieser, *Org. Syntheses*, **11**, 12 (1931), John Wiley & Sons, New York.
20. Vorozhtzov and Bogdanov, *Ber.*, **62B**, 68 (1929); Bogdanov and Leukov, *J. Gen. Chem. (U.S.S.R.)*, **5**, 18 (1935); *C.A.*, **29**, 4756 (1935).
21. Bogdanov, *J. Gen. Chem. (U.S.S.R.)*, **2**, 9, 770 (1932); *C.A.*, **26**, 5297 (1932); **27**, 2684 (1933).
22. Lantz and Mingasson, *Compt. rend.*, **192**, 1664 (1931).
23*a*. Battegay and Riesz, *Bull. soc. chim.*, **51**, 902 (1932). *b*. Kogan, *Ber.*, **64B**, 2150 (1931).
24. Lantz and Wahl, *Compt. rend.*, **180**, 1668 (1925); U. S. pat., 1,657,809, *C.A.*, **22**, 966 (1928).
25. Vorozhtzov, *Ann. chim.*, **6**, 381 (1916); **7**, 50 (1917); *J. Russ. Phys.-Chem. Soc.*, **47**, 1669 (1915); *C.A.*, **10**, 2896 (1916).
26. Bucherer and co-workers, *J. prakt. Chem.*, [2] **69**, 49 (1904); **70**, 345 (1904); **71**, 433 (1905); **75**, 249 (1907); **77**, 403 (1908); **79**, 369 (1909); **81**, 1 (1910); **103**, 253 (1922); Vorozhtzov with Kassatkin, *Ber.*, **62B**, 57 (1929); Vorozhtzov, *Bull. soc. chim.*, **35**, 996 (1924); *C.A.*, **17**, 1636 (1922); Fuchs and Pirak, *Ber.*, **59B**, 2454 (1926); Fuchs and Stix, *Ber.*, **65B**, 658 (1922).
27. Engel, *J. Am. Chem. Soc.*, **51**, 2986, 3483 (1929).
28. Hunter and Sprung, *ibid.*, **63**, 1443 (1931).
29*a*. Piria, *Ann.*, **78**, 31 (1851). *b*. Hilkenkamp, *Ann.*, **95**, 86 (1855). *c*. Carius, *Z. Chem.*, 632 (1861). *d*. Smit, *Ber.*, **8**, 1442 (1875).
30. Seyewetz and Vigant, *Compt. rend.*, **174**, 296 (1922).
31. Hunter and Sprung, *J. Am. Chem. Soc.*, **53**, 1432, 1443 (1931).
32. E. and H. Erdmann, German pat., 65,240, *Frdl.*, **3**, 41 (1891); Meister, Lucius, and Brüning, German pat., 78,772, *Frdl.*, **4**, 305 (1894); German pat., 126,804, *Frdl.*, **6**, 384 (1901); A. Fischesser and Co., German pat., 79,577, *Frdl.*, **4**, 565 (1894); Nietzki, German pat., 86,097, *Frdl.*, **4**, 90 (1895); Walter, German pat., 109,497, *Frdl.*, **5**, 70 (1899); Bayer and Co., German pat., 103,395, *Frdl.*, **6**, 252 (1897); Turner, German pat., 123,115, *Frdl.*, **6**, 171 (1900); Bayer and Co., German pat., 113,944, *Frdl.*, **6**, 184 (1900); Weil, German pat., 147,552, *Frdl.*, **7**, 58 (1902); German pat., 151,134, *Frdl.*, **7**, 61 (1902); Meister, Lucius, and Brüning, German pat., 92,082, *Frdl.*, **4**, 528 (1895); German pat., 215,338, *Frdl.*, **10**, 182 (1910).
33*a*. Weil and Moser, *Ber.*, **55B**, 732 (1922). *b*. Bogdanov and Kheĭfets, *J. Gen. Chem. (U.S.S.R.)*, **7**, 911 (1937); *C.A.*, **31**, 5777 (1937).
34. Weil and Wassermann, *Ber.*, **55B**, 2533 (1922).

35*a*. Nietzki and Helbach, *Ber.*, **29**, 2448 (1896). *b*. Gulinov, *Ukrainskii Khem. Zhur.*, **4**, Tech. Pt., 227 (1929); *C.A.*, **24**, 2449 (1930).

36. Gulinov, *C.A.*, **27**, 3929 (1933).

37. Bucherer and Barsch, *J. prakt. Chem.*, [2] **111**, 329 (1925).

38. Zahn and Eckert, U. S. pat., 1,674,351, *C.A.*, **22**, 2846 (1928).

39. Rosenmund and Struck, *Ber.*, **54B**, 439 (1921).

40. Moore and Tucker, *J. Am. Chem. Soc.*, **49**, 262 (1927).

41*a*. J. R. Geigy and Co., German pat., 88,952, *Chem. Zentr.*, I, 142 (1897). *b*. Scottish Dyes, Ltd., German pat., 516,674, *C.A.*, **25**, 2738 (1931). *c*. I. G. Farbenind. A.-G., French pat., 849,110, *C.A.*, **35**, 6270 (1941).

42*a*. Armstrong and Harrow, *J. Chem. Soc.*, **29**, 474 (1871). *b*. Marschalk, *Bull. soc. chim.*, [4] **45**, 651 (1929).

43*a*. J. R. Geigy and Co., German pat., 94,504, *Chem. Zentr.*, I, 358 (1898). *b* Willgerodt, *J. prakt. Chem.*, [2] **32**, 117 (1885).

44. E. and H. Erdmann, German pat., 65,240, *Frdl.*, **3**, 41.

45. Laubenheimer, *Ber.*, **15**, 597 (1882).

46. Badische Anilin- und Sodafabrik, German pat., 77,192, *Frdl.*, **4**, 37.

47*a*. Marschalk and Ouroussoff, *Bull. soc. chim.*, [5] **2**, 1216 (1935). *b*. Sandqvist, *Ber.*, **50**, 775 (1917); *Ann.*, **392**, 76 (1912). *c*. Federov and Sheludyakova, *C.A.*, **33**, 4981 (1939).

48. Federov, *C.A.*, **23**, 3700 (1929).

49*a*. Bayer and Co., German pat., 164,292, *Frdl.*, **8**, 231; German pat., 167,169, *Frdl.*, **8**, 232. *b*. Locher and Fierz, *Helv. Chim. Acta*, **10**, 642 (1927).

50. Stein and Baumann, German pat., 583,936, *C.A.*, **28**, 783 (1934).

51. I. G. Farbenind. A.-G., French pat., 753,138, *C.A.*, **28**, 783 (1934).

52*a*. I. G. Farbenind. A.-G., British pat., 416,291, *C.A.*, **29**, 819 (1935); French pat., 772,910, *C.A.*, **29**, 1438 (1935). *b*. Dohrn and Diedrich, German pat., 564,786, *C.A.*, **27**, 1010 (1933). *c*. Besthorn and Geisselbrecht, *Ber.*, **53B**, 1017 (1920). *d*. Lehmstedt and Wirth, *Ber.*, **61B**, 2044 (1928).

53. Landsberg, *Ber.*, **23**, 1454 (1890).

54. Müller and Wiesinger, *Ber.*, **12**, 1348 (1879); Griffin, *Am. Chem. J.*, **19**, 177 (1897).

55. Wiesinger and Vollbrecht, *Ber.*, **10**, 1715 (1877).

56*a*. Tröger and Thomas, *J. prakt. Chem.*, [2] **110**, 54 (1925). *b*. J. R. Geigy A.-G., Swiss pats., 199,957–199,959, *C.A.*, **32**, 4179 (1938).

57. Vogt, *Ann.*, **119**, 151 (1861).

58. Otto and Ostrop, *Ann.*, **141**, 370 (1867).

59. Otto and Gruber, *Ann.*, **145**, 19 (1868).

60. Willgerodt and Mohr, *J. prakt. Chem.*, [2] **34**, 116 (1886).

61*a*. Wohlfahrt, *ibid.*, [2] **66**, 554 (1902). *b*. Wertheim, *Org. Syntheses*, **15**, 55 (1935), John Wiley & Sons, New York.

62. Blanksma, *Rec. trav. chim.*, **20**, 125 (1901); **19**, 111 (1900); *Verslag. Akad. Wettenschappen Amsterdam*, **8**, 299 (1899); **9**, 401 (1900); Elgersma, *Rec. trav. chim.*, **48**, 752 (1929).

63. Blanksma, *ibid.*, **24**, 322 (1905).

64. Blanksma, *ibid.*, **27**, 48 (1908).

65*a*. Zincke, *Ann.*, **400**, 10 (1913). *b*. Fierz-David, Schlittler, and Waldmann, *Helv. Chim. Acta*, **12**, 663 (1929). *c*. Ruggli and Merz, *ibid.*, **12**, 71 (1929).

66*a*. Holleman, *Rec. trav. chim.*, **40**, 446 (1921). *b*. Jackson and Earle, *Am Chem. J.*, **29**, 218 (1903).

67*a*. Koenigs and Kinne, *Ber.*, **54B**, 1357 (1921). *b*. Sucharda and Troszkiewicz, *Roczniki Chem.*, **12**, 493 (1932); *C.A.*, **27**, 5076 (1933). *c*. Dohrn and Diedrich, German pat., 564,786, *C.A.*, **27**, 1010 (1933). *d*. Besthorn and Geisselbrecht, *Ber.*, **53B**, 1017 (1920).

68. Holleman and Caland, *Ber.*, **44**, 2505 (1911).

69. Wynne and Bruce, *J. Chem. Soc.*, **73**, 751 (1898); Klason, *Ber.*, **20**, 353 (1887).

70*a*. Pfannenstill, *Ber.*, **27R**, 889 (1894); Holleman, *Rec. trav. chim.*, **42**, 839 (1923). *b*. Hurtley and Smiles, *J. Chem. Soc.*, 1821 (1926); Holleman, *Rec. trav. chim.*, **29**, 416 (1910); **40**, 446 (1921); Pollak, *Monatsh.*, **34**, 1673 (1913).

71. Armstrong and Wynne, *Chem. News*, **67**, 299 (1893).

72. Bayer and Co., German pat., 70,296, *Frdl.*, **3**, 421; Leuckart, *J. prakt. Chem.*, [2] **41**, 218 (1890).

73. Moschner, *Ber.*, **34**, 1260 (1901).

74*a*. Morgan, Micklethwait, and Winfield, *J. Chem. Soc.*, **85**, 757 (1904). *b*. Gattermann, *Ber.*, **32**, 1156 (1899).

75. Smiles and De Rossignol, *J. Chem. Soc.*, **93**, 758 (1908).

76. Laves, *Ber.*, **23**, 1415 (1890).

77. R. and W. Otto, *J. prakt. Chem.*, [2] **36**, 410 (1887).

78. Otto, *ibid.*, [2] **51**, 289 (1895).

79. Otto, *ibid.*, [2] **30**, 351 (1884).

80. Pauly and Otto, *Ber.*, **11**, 2071 (1878).

81. Zincke and Frohneberg, *Ber.*, **42**, 2722 (1909).

82. Zincke and Röse, *Ann.*, **406**, 134 (1914).

83. Fichter and Wenk, *Ber.*, **45**, 1382 (1912).

84. Zincke and Frohneberg, *Ber.*, **43**, 841 (1910).

85. Ullmann and Lehner, *Ber.*, **38**, 732 (1905).

86. Otto and v. Gruber, *Ann.*, **142**, 96 (1867).

87*a*. Mizuch, *J. Gen. Chem.* (*U.S.S.R.*), **10**, 844 (1940); *C.A.*, **35**, 2509 (1941). *b*. I. G. Farbenind. A.-G., British pat., 416,291, *C.A.*, **29**, 819 (1935).

88. Gubelmann, Weiland, and Stallmann, U. S. pat., 1,810,013, *C.A.*, **25**, 4558 (1931).

89. Barnes and Pyman, *J. Chem. Soc.*, 2711 (1927).

90. Jacobsen, *Ber.*, **10**, 1011 (1877).

91. Hälssig, *J. prakt. Chem.*, [2] **56**, 214 (1897); Heiduschka, *ibid.*, [2] **81**, 321 (1910).

92. Haitinger, *Monatsh.*, **4**, 173 (1883).

D. MISCELLANEOUS SYNTHESES OF SULFONIC ACIDS*

The methods of preparing sulfonic acids thus far considered deal only with the formation of the sulfo group. In this section reactions that have been used to convert one sulfonic acid into another by the loss or gain of other substituents are described. Since most of these reactions are of minor importance from the standpoint of sulfur chemistry they are not discussed at length.

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* References for this section on p. 377.

The behavior of sulfonic acids toward halogenation, nitration, and alkali fusion is outlined in the chapter on "Reactions of Sulfonic Acids," because usually these reactions involve the sulfo group.

Removal of Halogens by Reduction. A halogen atom attached to the aromatic nucleus in a water soluble compound such as a sulfonic acid is replaceable by hydrogen through the action of an active reducing agent. For derivatives of benzene the sulfonic acid grouping is apparently not appreciably affected by reducing agents while in the naphthalene series the α-sulfo groups are removed as sulfurous acid, the β-sulfonic acids being unaffected. The reducing agents most commonly employed are sodium amalgam in water or alcohol solution, and zinc dust with an aqueous solution of ammonium or an alkali hydroxide. Although the sodium amalgam method may be satisfactory where a small quantity of material is reduced, it is too tedious for the preparation of appreciable amounts of a compound, since a day to several weeks is necessary to complete the reaction.

The sodium amalgam reduction has apparently not been tried with fluorosulfonic acids. Chlorosulfonic acids derived from benzene,[1] toluene,[2] and xylene[3] have been dehalogenated successfully. Bromosulfonic acids react more rapidly than the chloro compounds and more of them have been investigated. These include derivatives of toluene,[4] *o*-xylene,[5] *p*-cymene,[6] *m*-cymene,[7] and 1,2,4-trimethylbenzene.[8] It also is possible to remove the bromine from sulfonamides as was shown for some bromo-*m*-xylenesulfonamides.[9] Reduction of 4-bromonaphthalene-1-sulfonic acid[10] removes both the halogen and sulfo groups. Iodine is readily eliminated from 4-iodotoluene-3,5-disulfonic acid.[11a]

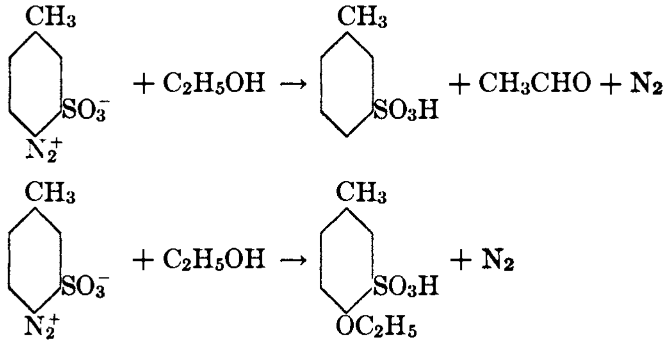
It has been reported in the patent literature[11b] that the halogen can be removed from a variety of chlorine and bromine compounds by treatment with hydrogen in the presence of a catalyst such as nickel in aqueous alkaline solution.

Zinc and ammonium hydroxide have been used to remove the chlorine from some dichloro-*m*-xylenesulfonic acids,[12] the bromine from a variety of alkylated bromobenzenesulfonic acids,[13] and the iodine from a few iodoalkylbenzenesulfonic acids.[14] Sodium, potassium, or barium hydroxide[15] and zinc have been utilized in reducing a number of alkylbromobenzenesulfonic acids.

Apparently the only derivative of a halobenzenesulfonic acid containing other than an alkyl group that has been treated with zinc and sodium hydroxide is 4-bromophenetole-2-sulfonic acid.[16]

Removal of Amino Groups. The powerful directive influence of the amino group in sulfonation reactions and the ease with which it is replaced by hydrogen through the reduction of the corresponding diazonium salt furnish a method of importance in obtaining sulfonic acids otherwise difficultly accessible.

The removal of a diazonium group has been accomplished in several ways. The most frequently utilized procedure is to boil the diazonium compound with methyl or ethyl alcohols. Two difficulties are encountered in applying this method. The first, a serious one, is that the reduction is accompanied by a side reaction in which an alkoxy group replaces the nitrogen and the resulting mixture of sulfonic acids is difficult to separate.



A second minor difficulty is the necessity for isolation of the pure diazonium salt or preparing it in anhydrous alcohol solution. In a detailed study of the preparation of toluene-3-sulfonic acid [17] the most satisfactory yields were obtained by the use of methanol in the presence of sodium carbonate or zinc dust. The presence of cuprous oxide or copper powder might be of advantage in these reductions.

The amino group has been removed from a variety of aminosulfonic acids by this diazotization-alcohol reduction method. These include derivatives of benzene,[18] toluene,[19] *m*-xylene,[20] and a number of halogen and nitro derivatives of benzene [21] and toluene.[22] Phenol-*o*-sulfonic acid results from heating diazotized *p*-aminophenol-*o*-sulfonic acid [23] with alcohol to 150°. Several biphenyldisulfonic acids have been obtained by heating tetrazotized benzidine derivatives with alcohol.[24] The presence of copper powder seems to facilitate the reaction, a 90% yield of biphenyl-3,3′-disulfonic acid resulting by this procedure. There are also a few instances in which the alcohol reduction method has been used in the naphthalene series.[25]

Other reagents, which, however, have had a limited use in reductive removal of the diazonium group, are formic acid,[25g, 26] sodium stannite in alkaline solution,[27a] an alkaline *d*-glucose solution,[27b] and ferrous hydroxide.[27c]

An indirect method for removing the diazonium group which in some cases gives better yields than the alcohol reduction procedure and is more generally applicable, consists in reduction of the diazonium salt to the hydrazine and oxidation of the latter with any one of a number of reagents including cupric sulfate, ferric chloride, and potassium chromate. This has been applied to derivatives of toluene,[28] *m*-diiodobenzene,[29] tetralin,[30] naphthalene,[25a, 31a] and stilbene.[31b]

Halosulfonic Acids by Diazo Reaction. The replacement of an amino group by a halogen through the diazo reaction offers little of interest from the standpoint of sulfur chemistry. The sulfo group has little or no apparent influence upon the reaction. Some of the preparations were made before the discovery of the catalytic value of copper or a copper salt and hence the yields were probably low, although in most reactions they were not recorded.

4-Fluorotoluene-2-sulfonic acid[32] and 4- and 5-fluoronaphthalene-1-sulfonic acids[33] have been obtained by treating the diazonium salts with warm 40% hydrofluoric acid.

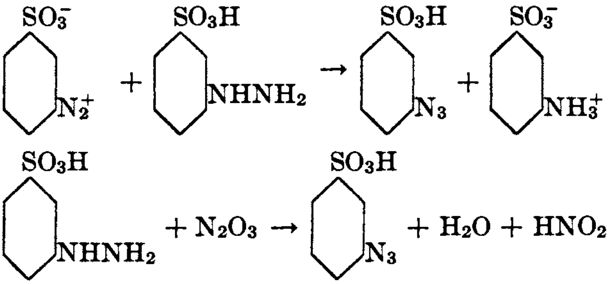
The three chlorobenzenesulfonic acids,[34] four chlorotoluenesulfonic acids,[35] a chloro-*p*-cymenesulfonic acid,[36] a dichlorobiphenylsulfonic acid,[37] and a large number of chloronaphthalenesulfonic acids,[38] have been prepared from the amino compounds. Conversion of 2,4,5-trichloro-3-aminobenzenesulfonic acid into the tetrachloro compound[39] indicates that halogens *ortho* to the amino group do not limit the reaction. The chlorine of 3-chloro-6-bromobenzenesulfonic acid also may be introduced through the diazo reaction.[40]

The chlorine of a number of chloro and dichloronaphthalenedisulfonic acids,[41] a chloronaphthalenetrisulfonic acid,[42] and the second chlorine of some dichloronaphthalenesulfonic acids[25a, 43] have all been introduced by the diazo reaction.

The preparation of bromosulfonic acids from the corresponding amino compounds was used by the earlier investigators in preparing many of the bromine derivatives of benzenesulfonic acid.[44] The method has been used somewhat less frequently in synthesizing derivatives of toluene,[45] *m*-xylene,[46] *p*-cymene,[47] biphenyl,[48] and naphthalene.[49]

In the preparation of iodosulfonic acids from diazonium compounds it is not necessary to use a copper catalyst and the yields are usually excellent. Various iodo derivatives of benzenesulfonic acid,[50] 4-iodotoluene-2-sulfonic acid,[32] 4-iodotoluene-3,5-disulfonic acid,[51] and iodo derivatives of α- and β-naphthalenesulfonic acids[52] have been prepared.

Azidosulfonic Acids. Analogous in some respects to the preparation of halosulfonic acids is that of the azido compounds.[53] Only a few substances of this class have been made.



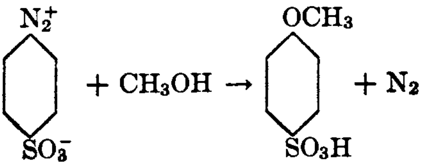
Hydroxysulfonic Acids from Diazonium Salts. The decomposition of diazonium salts containing one or more sulfo groups to give phenolsulfonic acids has been of value chiefly in obtaining *m*-hydroxysulfonic acids but has been applied in other instances where a product free from isomers was desired.

The three phenolsulfonic acids,[54] 2,6-dibromophenol-4-sulfonic acid,[54a] several cresol mono[55] and disulfonic[56] acids, two xylenolsulfonic acids,[57a, b] and several nitrophenolsulfonic acids[57c] have been obtained in this manner.

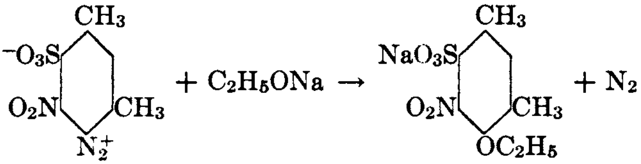
The hydrolysis of diazonium compounds has been applied many times in the naphthalene series to obtain hydroxysulfonic acids of value as dye intermediates. For details reference must be made to the original literature.[58]

The preparation of 1-hydroxy-4-haloanthraquinonesulfonic acids from the 1-amino compounds by diazotization and boiling with a copper sulfate solution has been patented.[59a] Hydroxypyridinesulfonic acids[59b] have also been made from the amino compounds.

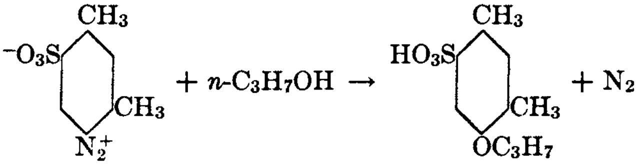
Alkoxysulfonic Acids from Diazonium Salts. Closely related to the hydrolysis of diazonium compounds to phenols is their reaction with alcohols to give ethers. The reaction gives satisfactory yields only with methanol, ethyl alcohol giving more of the reduction product in which the diazo group has been replaced by hydrogen. The reaction with methanol has frequently been carried out under pressure slightly above atmospheric as this gives better yields.



Methoxy derivatives of benzenesulfonic acid,[60] toluenesulfonic acids,[61] and *m*-xylene-4-sulfonic acid,[62] and the ethoxy derivatives of a similar group of sulfonic acids [60c,61,63] have all been obtained by heating the diazonium sulfonate with the corresponding alcohol. As a variation in the procedure it is possible to use an alcoholic solution of sodium ethoxide.[64] In two examples the preparation of *n*-propoxy

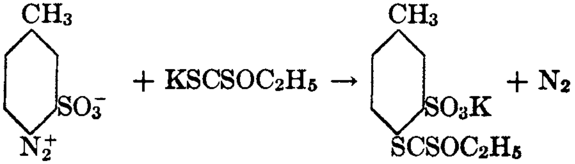


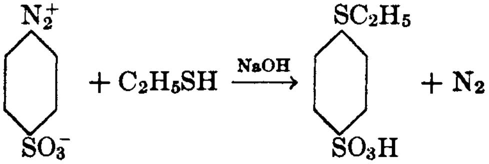
compounds from the alcohol and diazonium salt has been mentioned.[62,65]

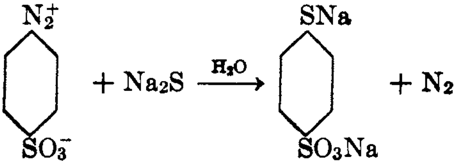


When diazomesitylenesulfonic acid is heated to 100° with glycerol, a mixture of products results in which the di-ethers of glycerol predominate.[66]

Thiophenolsulfonic Acids and Related Compounds. Diazotized aminosulfonic acids react with a variety of sulfur compounds including potassium ethyl xanthate,[67a] sodium sulfide,[67b] and ethanethiol.[67c] Examples are shown in the equations.







REFERENCES FOR D. MISCELLANEOUS SYNTHESES OF SULFONIC ACIDS

1. Glutz, *Ann.*, **143**, 185 (1867).
2. Wynne and Bruce, *J. Chem. Soc.*, **73**, 776 (1898).
3. Krüger, *Ber.*, **18**, 1759 (1885); Klages, *Ber.*, **29**, 310 (1896).
4. Hübner and Müller, *Ann.*, **169**, 47 (1873); Neville and Winther, *J. Chem. Soc.*, **37**, 628 (1880); *Ber.*, **13**, 1947 (1880); Griffin, *Am. Chem. J.*, **19**, 198 (1897); Pagel, *Ann.*, **176**, 294 (1875); Hübner and Terry, *Ann.*, **169**, 27 (1873); Hübner and Post, *Ann.*, **169**, 47 (1873); Kornatzki, *Ann.*, **221**, 199 (1883).
5. Jacobsen, *Ber.*, **17**, 2374 (1884).
6. Remsen and Day, *Am. Chem. J.*, **5**, 154 (1883).
7. Kelbe and Czarnomski, *Ann.*, **235**, 285 (1886).
8. Kelbe and Pathe, *Ber.*, **19**, 1555 (1886).
9. Jacobsen and Weinberg, *Ber.*, **11**, 1534 (1878); Junghahn, *Ber.*, **35**, 3757 (1902).
10. Meldola, *Ber.*, **12**, 1964 (1879).

11*a*. Richter, *Ann.*, **230**, 326 (1885). *b*. Schöllkopf, U. S. pat., 1,645,974, *C.A.*, **22**, 91 (1928).

12. Koch, *Ber.*, **23**, 2319 (1890).
13. Sempotowski, *Ber.*, **22**, 2668 (1889); Jacobsen, *Ber.*, **21**, 2825 (1888); **22**, 1582 (1889); **19**, 1218 (1886); Jacobsen and Deike, *Ber.*, **20**, 903 (1887); Wischin, *Ber.*, **23**, 3116 (1890); Kelbe and Koschnitzky, *Ber.*, **19**, 1733 (1886); Dinesmann, German pat., 125,097, *Chem. Zentr.*, II, 1030 (1901); Töhl and Geyger, *Ber.*, **25**, 1538 (1892).
14. Bauch, *Ber.*, **23**, 3119 (1890); Töhl and Bauch, *Ber.*, **26**, 1107 (1893).
15. Noyes and Walker, *Am. Chem. J.*, **8**, 187 (1886); Moody, *Chem. News*, **71**, 197 (1895); **79**, 81 (1899); **58**, 21 (1888); **67**, 34 (1893); Jacobsen and Weinberg, *Ber.*, **11**, 1534 (1878); Armstrong and Napper, *Chem. News*, **82**, 46 (1900); Rheinische Campherfabrik, German pat., 303,095, *Chem. Zentr.*, I, 498 (1918).
16. Moody, *Chem. News*, **67**, 35 (1893).
17. Griffin, *Am. Chem. J.*, **19**, 163 (1897); see also Vallin, *Ber.*, **19**, 2952 (1886); Klason, *Ber.*, **19**, 2887 (1886); v. Pechmann, *Ann.*, **173**, 202 (1874).
18. Schmitt, *Ann.*, **120**, 152 (1861); Ador and Meyer, *Ann.*, **159**, 8 (1871).
19. Ascher, *Ann.*, **161**, 8 (1872); Jenssen, *Ann.*, **172**, 235 (1874); Nevile and Winther, *Ber.*, **15**, 2993 (1882); v. Pechmann, *Ann.*, **173**, 214 (1874); Foth, *Ann.*, **230**, 305 (1885); Hirwe and Jambhekar, *J. Indian Chem. Soc.*, **11**, 239 (1934).
20. Armstrong and Wilson, *Chem. News*, **83**, 46 (1901); Zincke and Maue, *Ann.*, **339**, 216 (1905).
21. Paal, *Ber.*, **34**, 2754 (1901); Bässmann, *Ann.*, **191**, 232 (1878); Langfurth, *Ann.*, **191**, 184 (1878); Limpricht, *Ann.*, **181**, 201 (1876); Schmitt, *Ann.*,

120, 158 (1861); Lenz, *Ann.*, **181**, 25 (1876); Knuth, *Ann.*, **185**, 186 (1877); Boyle, *J. Chem. Soc.*, **96**, 1694 (1909); **99**, 326 (1911); Elgersma, *Rec. trav. chim.*, 48, 752 (1929).

22. Nevile and Winther, *Ber.*, **13**, 1944 (1880); v. Pechmann, *Ann.*, **173**, 212 (1874); Weckwarth, *Ann.*, **172**, 196 (1874).

23. Post, *Ber.*, **8**, 1549 (1875).

24. Limpricht, *Ann.*, **261**, 327 (1891); Schultz and Kohlhaus, *Ber.*, **39**, 3342 (1906); Helle, *Ann.*, **270**, 364 (1892).

25*a*. Hellstrom, "Öfersigt Af Kongl Vetenskapps-Akademiens forhandlingar," 1889, p. 113. *b*. Badische Anilin- und Sodafabrik, German pat., 57,910, *Frdl.*, **2**, 252. *c*. Kalle and Co., German pat., 62,634, *Frdl.*, **3**, 431. *d*. Pfitzinger and Duisberg, *Ber.*, **22**, 398 (1889). *e*. Armstrong and Wynne, *Ber.*, **24R**, 655, 658, 707, 716 (1891). *f*. Badische Anilin- und Sodafabrik, German pat., 79,082, *Frdl.*, **3**, 702. *g*. Tobias, *Ber.*, **23**, 1628 (1890); Morgan and Jones, *J. Soc. Chem. Ind.*, **42**, 96 (1923).

26. Armstrong and Wynne, *Ber.*, **24R**, 708, 709, 716, 718 (1891).

27*a*. Friedländer, *Ber.*, **22**, 587 (1889). *b*. Benade, Keller, and Berger, U. S. pat., 2,230,791, *C.A.*, **36**, 3268 (1941). *c*. Berger, German pat., 698,318, *C.A.*, **36**, 6269 (1941).

28. Brackett and Hayes, *Am. Chem. J.*, **9**, 402 (1887); Holleman, *Rec. trav. chim.*, **24**, 207 (1905); Hasse, *Ann.*, **230**, 295 (1885); Wynne and Bruce, *J. Chem. Soc.*, **73**, 739 (1898).

29. Boyle, *ibid.*, **95**, 1694 (1909).

30. Morgan, Micklethwait, and Winfield, *ibid.*, **85**, 757 (1904).

31*a*. Armstrong and Wynne, *Ber.*, **24R**, 658, 707, 716 (1891). *b*. Bender and Schultz, *Ber.*, **19**, 3236 (1886); Leonhardt and Co., German pat., 40,575, *Frdl.*, **1**, 512.

32. de Roode, *Am. Chem. J.*, **13**, 219 (1891).

33. Mauzelius, *Ber.*, **22**, 1844 (1839); "Öfersigt Af Kongl Vetenskaps-Akademiens forhandlingar," Stockholm, 1890, p. 441.

34. Bahlmann, *Ann.*, **186**, 325 (1877); Kieselinsky, *Ann.*, **180**, 108 (1876); Goslich, *Ann.*, **180**, 106 (1876).

35. Wynne, *J. Chem. Soc.*, **61**, 1040 (1892); Wynne and Bruce, *ibid.*, **73**, 761 (1898); Jenssen, *Ann.*, **172**, **235** (1874).

36. Errera, *Gazz. chim. ital.*, **19**, 539 (1889); **21**, I, 70 (1891).

37. Elbs and Wohlfahrt, *J. prakt. Chem.*, [2] 66, 570 (1902).

38. Forsling, *Ber.*, **19**, 1716 (1886); **20**, 80, 2105 (1887); **21**, **2802** (1888); Cleve, *Ber.*, **20**, 74 (1887); **21**, 3273 (1888); **24**, 3474 (1891); **26**, **2481** (1892); *Bull. soc. chim.*, [2] **26**, **241**, 540 (1876); Armstrong, *Chem. News*, **68**, **295** (1888); Armstrong and Wynne, *ibid.*, **59**, 188 (1889); **73**, 54 (1896); Houlding, *Ber.*, **24R**, 705 (1891); Mauzelius, *Ber.*, **20**, **3**401 (1887); **65**, 49 (1922); Jacchia, *Ann.*, **323**, 127 (1902); Cumming and Muir, *J. Roy. Tech. Coll. Glasgow*, **3**, 223 (1934); *C.A.*, **28**, 4409 (1934).

39. Nölting and Battegay, *Ber.*, **39**, 81 (1906).

40. Armstrong and Briggs, *Chem. News*, **66**, 139 (1892).

41*a*. Forsling, *Ber.*, **21**, 3497 (1888). *b*. Armstrong and Wynne, *Chem. News*, **62**, 163 (1890); **61**, **92** (1890); **73**, 55 (1896); **63**, 124 (1891); **71**, **254** (1895); Friedländer and Kielbasinski, *Ber.*, **29**, 1978, **2574** (1896).

42. Armstrong and Wynne, *Chem. News*, **62**, 163 (1890).

43. Cleve, *Ber.*, **26**, **2481** (1892); *Chem.-Ztg.*, **17**, **398**, 758 (1893); Armstrong and Wynne, *Chem. News*, **69**, 189 (1889).

44. Bahlmann, *Ann.*, **181**, 203 (1876); Berndsen, *Ann.*, **177**, 92 (1875); Meyer, *Ann.*, **156**, 291 (1870); Reinke, *Ann.*, **186**, 288 (1877); Thomas, *Ann.*, **186**, 130 (1877); Bahlmann, *Ann.*, **186**, 312 (1877); Langfurth, *Ann.*, **191**, 179 (1878); Spiegelberg, *Ann.*, **197**, 263, 292 (1879); Sachse, *Ann.*, **188**, 153 (1877); Jackson and Earle, *Am. Chem. J.*, **29**, 217 (1903); Lenz, *Ann.*, **181**, 25, 45 (1876); Beckurts, *Ann.*, **181**, 216 (1876); Heinzelmann and Spiegelberg, *Ann.*, **197**, 306 (1879); Armstrong and Briggs, *Chem. News*, **65**, 139 (1892); Goslich, *Ann.*, **180**, 96 (1876); Knuth, *Ann.*, **186**, 296 (1877); Zander, *Ann.*, **198**, 10, 28 (1879); Heinzelmann, *Ann.*, **190**, 227 (1878); **188**, 177 (1877); Borns, *Ann.*, **187**, 364 (1877).

45. Jenssen, *Ann.*, **172**, 235 (1874); Wynne, *J. Chem. Soc.*, **61**, 1040 (1892); v. Pechmann, *Ann.*, **173**, 202 (1874); Pagel, *Ann.*, **176**, 297 (1875); Claus and Immel, *Ann.*, **265**, 77 (1891); Hayduck, *Ann.*, **172**, 205 (1874); **174**, 354 (1874); Richter, *Ann.*, **230**, 326 (1885); Schafer, *Ann.*, **174**, 365 (1874); Hayduck, *Ann.*, **172**, 219 (1874).

46. Moody, *Chem. News*, **65**, 60 (1892); Junghahn, *Ber.*, **35**, 3753 (1902); Nölting and Kohn, *Ber.*, **19**, 139 (1886); Sartig, *Ann.*, **230**, 335 (1885).

47. Errera, *Gazz. chim. ital.*, **19**, 539 (1889); **21**, I, 70 (1891); Widman, *Ber.*, **19**, 248 (1886).

48. Limpricht and Rodatz, *Ber.*, **14**, 1360 (1881).

49. Mauzelius, *Ber.*, **20**, 3405 (1887); Houlding, *Ber.*, **24R**, 705 (1891); Cleve, *Bull. soc. chim.*, [2] **26**, 540 (1876); Forsling, *Ber.*, **22**, 619, 1402 (1889); Lindall, *Chem. News*, **60**, 58 (1889).

50. Langmuir, *Ber.*, **28**, 95 (1895); Bahlmann, *Ann.*, **186**, 325 (1877); Lenz, *Ber.*, **10**, 1135 (1877); Boyle, *J. Chem. Soc.*, **95**, 1694, 1708 (1909); 99, 326 (1911); Suter and Scrutchfield, *J. Org. Chem.*, **1**, 189 (1936).

51. Richter, *Ann.*, **230**, 326 (1885).

52. Armstrong, *Chem. News*, **56**, 241 (1887); Houlding, *Chem. News*, **59**, 266 (1889); Mauzelius, *Ber.*, **22**, 2820 (1889); Armstrong and Wynne, *Chem. News*, **60**, 58 (1889); Chem. Fab. vorm Sandoz, British pat., 393,238, *C.A.*, **27**, 5756 (1933); 425,752, *C.A.*, **29**, 5461 (1935); Cumming and Muir, *J. Roy. Tech. Coll. Glasgow*, **3**, 223 (1934); *C.A.*, **28**, 4409 (1934).

53. Limpricht and Newman, *Ber.*, **21**, 3410 (1888); Newman, *Ber.*, **21**, 3416 (1888); Griess, *Ber.*, **20**, 1529 (1887); Nölting and Michel, *Ber.*, **26**, 87, 91 (1893).

54*a*. Schmitt, *Ann.*, **120**, 148 (1861). *b*. Schultz and Ichenhaeuser, *J. prakt. Chem.*, [2] **77**, 114 (1908). *c*. Kreis, *Ann.*, **286**, 386 (1895).

55. Gerver, *Ann.*, **169**, 386 (1873); Nevile and Winther, *Ber.*, **13**, 1946 (1880); Hayduck, *Ann.*, **174**, 345 (1874); Schafer, *Ann.*, **174**, 361 (1874); v. Pechmann, *Ann.*, **173**, 203 (1874); Engelhardt and Latischinow, *Z. Chem.*, 619 (1869); Jenssen, *Ann.*, **172**, 237 (1874).

56. Griess, *J. Chem. Soc.*, **20**, 87 (1867); Richter, *Ann.*, **230**, 322 (1885); Hasse, *Ann.*, **230**, 293 (1885).

57*a*. Sartig, *Ann.*, **230**, 335 (1885). *b*. Junghahn, *Ber.*, **35**, 3762 (1902). *c*. Nietski and Helbach, *Ber.*, **29**, 2450 (1896); Limpricht, *Ber.*, **8**, 289 (1875).

58. *1-Naphtholsulfonic acids:* Cleve, *Ber.*, **24**, 3476 (1891); Reverdin and de la Harpe, *Ber.*, **25**, 1403 (1892); Gattermann and Schulze, *Ber.*, **30**, 54 (1897); Cleve, *Bull. soc. chim.*, [2] **26**, 241 (1876); **24**, 512 (1875); Nevile and Winther, *Ber.*, **13**, 1949 (1880); Verein, Chem. Fabr. Mannheim, German pat., 26,012, *Frdl.*, I, 391; Bucherer, *J. prakt. Chem.*, [2] **70**, 345

(1904); Bayer and Co., German pat., 109,102, *Frdl.*, **5**, 164; *Chem. Zentr.*, II, 359 (1900); Erdmann, *Ann.*, **247**, 341 (1888); Witt and Kaufmann, *Ber.*, **24**, 3157 (1891); Schultz, *Ber.*, 20, 3161 (1887); Bernthsen, *Ber.*, **23**, 3088 (1890); Höchster Farbwerke, German pat., 74,644, *Frdl.*, III, 423.

2-Naphtholsulfonic acids: Tobias, German pat., 29,084, *Frdl.*, **1**, 421; Claus, *J. prakt. Chem.*, [2] **39**, 315 (1889); *Ber.*, 22R., 336 (1889); Bayer and Dinsberg, *Ber.*, **20**, 1431 (1887); Badische Anilin- und Sodafabrik, German pat., 20,760, *Frdl.*, **1**, 419; Nietzki and Zühelen, *Ber.*, **22**, 453 (1889).

1-Naphtholdisulfonic acids: Bender, German pat., 32,291, *Frdl.*, **1**, 393; *Ber.*, 22, 993 (1889); Reverdin and de la Harpe, *Ber.*, **25**, 1400 (1892); Freund, German pat., 27,346, *Frdl.*, **1**, 431; Friedländer, and Taussig, *Ber.*, **30**, 1462 (1897); A.-G. für An.-Fabr., German pat., 45,776, *Frdl.*, 2, 253; Ewer and Pick, German pat., 52,724, *Frdl.*, **2**, 255; Badische Anilin- und Sodafabrik, German pat., 55,094, *Frdl.*, **2**, 257; Meister, Lucius, and Brüning, German pat., 71,494, *Frdl.*, **3**, 423; Bernthsen, *Ber.*, **22**, 3330 (1889); Dahl and Co., German pat., 41,957, *Frdl.*, **1**, 407; Armstrong and Wynne, *Ber.*, **24R**, 709 (1891); Schoelkopf Anilin Co., German pat., 40,571, *Frdl.*, **1**, 393; Badische Anilin- und Sodafabrik, 57,388, *Frdl.*, **2**, 260; Bernthsen, *Ber.*, **23**, 3090 (1890); Bucherer, *J. prakt. Chem.*, [2] **59**, 81 (1904); Bayer and Co., German pat., 70,857, *Frdl.*, **3**, 426; Kalle and Co., German pat., 82,563, *Frdl.*, 4, 519.

2-Naphtholdisulfonic acids: Bayer and Co., German pat., 77,866, *Frdl.*, 4, 595; Cassella and Co., German pat., 65,997, *Frdl.*, **3**, 444; Gans and Co., German pat., 35,019, *Frdl.*, **1**, 382.

Naphtholtrisulfonic acids: Kalle and Co., pat. appl. 12,732, *Frdl.*, **4**, 580; Koch, German pat., 56,058, *Frdl.*, **2**, 260; Meister, Lucius, and Brüning, German pat., 71,495, *Frdl.*, **3**, 423; Bayer and Co., pat. appl., 7,004, *Frdl.*, **4**, 560.

Nitronaphtholsulfonic acids: Finger, *J. prakt. Chem.*, [2] **79**, 443 (1909); Jacchia, *Ann.*, **323**, 122 (1902).

59*a*. Honold, U. S. pat., 1,886,017, *C.A.*, **27**, 1364 (1933); British pat., 342,551, *C.A.*, **25**, 5435 (1931). *b*. Roth, *Ann.*, **487**, 105 (1931).

60*a*. Shober, *Am. Chem. J.*, **15**, 391 (1893). *b*. Shober and Kiefer, *ibid.*, **17**, 456 (1895). *c*. Franklin, *ibid.*, **20**, 461 (1898).

61. Metcalf, *ibid.*, **15**, 305 (1893); Parks, *ibid.*, **15**, 321 (1893); Hayduck, *Ann.*, **172**, 217 (1874); Limpricht and Heffter, *Ann.*, **221**, 350 (1883).

62. Shober and Kiefer, *Am. Chem. J.*, **19**, 386 (1897).

63. Zander, *Ann.*, **198**, **25** (1879); Schultz, *Ber.*, **39**, 3347 (1906); Remsen and Dashiell, *Am. Chem. J.*, **15**, 105 (1893); Remsen and Palmer, *ibid.*, 8, 245 (1886); Errera, *Gazz. chim. ital.*, **21**, I, 69, (1891); Widman, *Ber.*, **19**, 247 (1886); Junghahn, *Ber.*, **35**, 3762 (1902); Sartig, *Ann.*, **230**, 342 (1885); Nevile and Winther, *J. Chem. Soc.*, **37**, 638 (1880); *Ber.*, **13**, 1947 (1880).

64. Foth, *Ann.*, **230**, 306 (1885); Sartig, *Ann.*, **230**, 342 (1885).

65. Metcalf, *Am. Chem. J.*, **15**, 317 (1893).

66. Jaroszewicz and Sucharda, *C.A.*, **29**, 6219 (1935).

67*a*. Wynne and Bruce, *J. Chem. Soc.*, **73**, 751 (1898); Walter, *Chem. News*, **72**, 47 (1895). *b*. Kalle and Co., German pat., 177,347, *Chem. Zentr.*, II, 1888 (1906); Armstrong and Wynne, *Chem. News*, **71**, **254** (1895). *c*. Stadler, *Ber.*, **17**, 2077 (1884).

CHAPTER IV

THE PROPERTIES AND REACTIONS OF AROMATIC SULFONIC ACIDS

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A. PHYSICAL PROPERTIES OF AROMATIC SULFONIC ACIDS AND THEIR SALTS

Only in a relatively few instances have aromatic sulfonic acids been isolated and their properties determined. Generally they are converted directly into salts which are more easily separated from a reaction mixture. Exceptions are sulfanilic acid and its analogs. However, benzenesulfonic acid, *p*-toluenesulfonic acid, and a few others have been studied in some detail.

Sulfonic Acids. The lower-molecular-weight sulfonic acids for the most part crystallize from water as hydrates and exist as deliquescent low-melting colorless solids. The solubility in water of an acid is generally greater than that of any of its salts. Sulfonic acids are less soluble in aqueous solutions of mineral acids than in water alone and they can be isolated in most cases by diluting the sulfonation mixture with a small amount of water. Purification by recrystallizing from concentrated hydrochloric acid has also been effective. Where sulfonation yields a mixture of isomeric acids it may be desirable to accomplish purification of an acid as the sulfonyl chloride which can then be hydrolyzed to the acid.

Aromatic sulfonic acids are highly ionized[1] in solutions of polar solvents. In glacial acetic acid,[1c] for example, *p*-toluene- and *p*-azobenzenesulfonic acids are less ionized than perchloric acid but more so than sulfuric acid when conductivity and catalytic decomposition of ethyl diazoacetate are the criteria. 2,4-Dimethoxybenzenesulfonic acid was somewhat less active than sulfuric acid but more so than nitric acid.

The equivalent conductivity of several isomeric nitro, dinitro, and nitrohalobenzenesulfonic acids[2] at infinite dilution is 377 ± 1. This confirms a rule stated earlier by Ostwald[3] that the conductivity is the same for isomeric ions; it also shows that variations in mobility among similar ions are small. 2,4-Dinitrobenzenesulfonic acid was the strongest acid investigated although they were all comparable to the strong inorganic acids.

In anhydrous formic acid[4] benzenesulfonic acid is nearly as strong as sulfuric acid which acts as a monobasic acid in this solvent. Benzenesulfonic acid is also a strong electrolyte in methyl or ethyl alcohol solution.[5]

The heat of neutralization of benzenesulfonic acid was measured by Berthelot.[6]

Metal Salts of Sulfonic Acids. Salts of sulfonic acids are customarily isolated from sulfonation mixtures in either one of two ways. The reaction mixture may be diluted with water and neutralized with calcium or barium carbonate to give the soluble sulfonate and insoluble sulfate. The sulfonate crystallizes upon evaporation of the filtrate. Addition of a soluble carbonate or sulfate to the filtrate will, of course, give any other desired sulfonate. A simpler procedure particularly useful in preparing an alkali metal salt is to pour the sulfonation mixture into a strong solution of the alkali chloride. The solubility of the aromatic sulfonate is decreased by the excess alkali chloride and also by the sulfuric acid remaining after the sulfonation is complete.[7] It was reported by Fischer[8] that the solubility of sodium β-naphthalenesulfonate in 5 *N* hydrochloric acid is less than one-half (2.42 g./100 g. H_2O) that in water (6.0 g./100 g. H_2O) at 23.9° so the effect is probably general for mineral acids. Cooke[9] has reported in great detail the solubility of sodium β-naphthalenesulfonate in water at various temperatures and in sodium chloride and sulfate solutions.

The solubility of sodium benzenesulfonate is not decreased greatly by sodium sulfate.[10] At 30° in pure water the value is 35.8 g./100 g. of solution while in 10% sodium sulfate it is reduced to 27.7 g.

A few methods employed in unusual cases to prepare alkali sulfonates may be mentioned. They are reported [11] to result from the action of alkali aluminum silicates with alkaline earth sulfonates. In the case of chloronitrobenzenesulfonates, adding sodium chloride to an aqueous solution of the calcium salt precipitates the sodium sulfonate.[12] An interesting procedure for obtaining a barium sulfonate is to neutralize a sulfonation mixture with zinc oxide and treat the resulting solution with barium sulfide.[13] This precipitates a mixture of zinc sulfide and barium sulfate (which may be used as a pigment in paints), leaving the sulfonate in solution. Sulfonic acids are slightly soluble in aromatic hydrocarbons and may be extracted from a sulfonation mixture by such a solvent, neutralization of the pure acid with the appropriate base giving any desired salt.[14]

The number of metal salts of aromatic sulfonic acids which have been described in the literature is large. The properties of the individual salts are not of general interest to the organic chemist and no attempt has been made here to survey this field. With few exceptions the salts are readily soluble in water and separate well from concentrated solutions as crystalline solids which are frequently hydrated. The dry salts have no definite melting points and are not therefore useful for identification purposes.

A systematic investigation of sulfonates of the elements in the second group of the periodic table has shown [15] that the water content of the hydrated salts is higher the larger the sulfonic acid molecule. For a given sulfonic acid the hydration is greater for beryllium, magnesium, zinc, and cadmium salts than for those of calcium, strontium, and barium. In concentrations of 0.1 to 0.5 *M* the acidity of the beryllium sulfonate solutions is less than that of the bromide or chloride but greater than that of the sulfate.

Aluminum compounds of hydroxysulfobenzoic and naphthoic acids differ from ordinary aluminum sulfonates in that the aluminum becomes part of the negative ions when the compounds are treated with a weak base.[16] These "aluminosulfonic acids" resist the action of acetic acid and are easily mercurated to give acetomercuri derivatives unaffected by alkali.

Salts of chloro-, bromo-, or nitrobenzenesulfonic acids form salts with the ammonia complexes of nickel, cobalt, copper, and other metals which are only slightly soluble in water.[17] The ammonia-free salts are much more soluble. On the other hand for sulfonic acids containing other substituents the complex ammonia salts are more soluble than those containing no ammonia.

Sulfonates of Organic Bases. Many of the salts obtained from aromatic sulfonic acids and amines have definite melting points and a low solubility in water. They are therefore useful in separating and identifying both amines and sulfonic acids. Thus quinizarin-2-sulfonic acid (rufianic acid, 1,4-dihydroxyanthraquinone-2-sulfonic acid) has been suggested [18] as a precipitant for a variety of simple aliphatic amines and amino acids. The sulfonic acid may be recovered by treating the amine salt with barium hydroxide and then decomposing the barium sulfonate with sulfuric acid. More recently [19] the solubility products of twenty-six sulfonic acid salts of various amino acids have been reported. The differences were great enough to make the salts useful for determination of certain of the amino acids in mixtures. Glycine and hydroxyproline come down with 5-nitronaphthalene-1-sulfonic acid, leucine may be determined with 2-bromotoluene-5-sulfonic acid or 2-naphthol-7-sulfonic acid, and phenylalanine precipitates with 2,5-dibromo- or 2,4,5-trichlorobenzenesulfonic acid even in the presence of excess leucine, arginine, and histidine.

Guaiacol- and creosotesulfonic acids give amorphous salts with the common alkaloids,[20] including morphine and codeine. The purification of crude sulfonic acids by precipitation with *n*-propyl- and cyclohexylamine as well as aromatic amines has been described.[21] Many sulfonic acids give crystalline salts with benzyl- [22] or *p*-chlorobenzylthiuronium chloride [23] which serve admirably for their identification. Since the sulfonic acids are easily prepared from most hydrocarbons the salts also serve to identify this class of compounds more conveniently than do other derivatives.

Many arylammonium sulfonates have been prepared either with the object of finding characteristic derivatives for the sulfonic acids or the amines, or in order to devise methods of separating mixtures obtained in sulfonations. In general the chance of finding an arylammonium sulfonate that is only slightly soluble in water and hence easy to isolate is much better than that of finding a metal sulfonate with this property. Since sulfonic acids are highly ionized the salts are hydrolyzed little, if any, more than those of hydrochloric acid. However, because of the weakly basic properties of aromatic amines the salts may be analyzed readily by titration with alkali using phenolphthalein as the indicator.[24] Many of the arylammonium sulfonates melt or decompose at definite temperatures.

The salts may be prepared by any one of several methods. Ambler [25] made some naphthalenesulfonates by mixing hot aqueous solutions of equivalent amounts of the free acid or its sodium or potassium salt and the amine hydrochloride; upon cooling the solution the salt separated. With more soluble salts other procedures may be useful. Forster and Keyworth[26] employed one or another of four methods: (1) the addition of a cold, concentrated solution of the amine hydrochloride to a similar solution of the sodium sulfonate; (2) mixing boiling solutions of these two reactants, concentrating the solution or evaporating to dryness and extracting with alcohol; (3) the addition of the amine sulfate solution to the solution of calcium sulfonate, the amine sulfonate separating out of the filtrate from the calcium sulfate; (4) mixing of the free acid and base in the presence of a little hydrochloric acid.

Detailed procedures for the qualitative detection of the common mono and disulfonic acids of naphthalene using the naphthylamines as precipitants have been worked out.[27]

In an investigation of the properties of a variety of arylammonium salts of benzenesulfonic acid[28] (Table I) it was observed that (1) the salts of diamines had higher melting points than those of monoamines; (2) the least soluble salts were those derived from amino derivatives of naphthalene and biphenyl; (3) salts of 2-aminoanthraquinone and *o*-nitro-*p*-toluidine could not be prepared; (4) basic salts of diamines could not be obtained pure; (5) N-substituted amines do not readily form salts of benzenesulfonic acid.

TABLE I

Arylammonium Benzenesulfonates

Amine	M.P. or Dec. P., °C. (Corr.)	Sol. in H_2O g./100 g. sol./°C.
$C_6H_5NH_2$	240	11.3/19
o-$CH_3C_6H_4NH_2$	176	20/19
m-$CH_3C_6H_4NH_2$	173	9.1/18
p-$CH_3C_6H_4NH_2$	205	7.4/16
1-$C_{10}H_7NH_2$	234	0.77/14
2-$C_{10}H_7NH_2$	248	0.59/14
1,2,4-$CH_3C_6H_3(NH_2)NO_2$	222	1.84/15
m-$O_2NC_6H_4NH_2$	236	3.85/15
1,3,4-$(CH_3)_2C_6H_3NH_2$	233	1.46/15
$(C_6H_4NH_2$-$p)_2$	>330	0.59/16
$[C_6H_3(CH_3)NH_2$-3,4$]_2$	310	1.45/15
$[C_6H_3(OCH_3)NH_2$-3,4$]_2$	277	2.11/18
m-$C_6H_4(NH_2)_2$	>320	19.0/17
p-$C_6H_4(NH_2)_2$	>320	2.57/10
p-$ClC_6H_4NH_2$	235	2.51/20
o-$ClC_6H_4NH_2$	204	....
1,2,4,5-$(CH_3)_3C_6H_2NH_2$	217	2.03/16
p-$CH_3OC_6H_4NH_2$	182	12.8/16
p-$C_2H_6OC_6H_4NH_2$	171	21.0/17

The salts of the nitrobenzenesulfonic acids [29] are much less soluble in water than those of benzenesulfonic acid. The arylamine salts of *p*-toluenesulfonic acid melt lower than the other sulfonates except the *α*-naphthalenesulfonates.[30] Since the necessary *p*-toluenesulfonic acid is readily available from the acid chloride the salts of this acid are convenient derivatives of the amines. The melting points are shown in Table II. Details of the preparations are to be found in the original.[30]

TABLE II

ARYLAMMONIUM *p*-TOLUENESULFONATES

Amine	M.P. of Salt, °C. (Corr.)	Amine	M.P. of Salt, °C. (Corr.)
$C_6H_6NH_2$	238.4	*o*-$NH_2C_6H_4COOH$	224.1–224.6
o-$CH_3C_6H_4NH_2$	189.7–190.5	*m*-$NH_2C_6H_4COOH$	255.9–256.5
m-$CH_3C_6H_4NH_2$	174.6–176.1	*p*-$NH_2C_6H_4COOH$	236.5–241.5
2,4,1-$(CH_3)_2C_6H_3NH_2$	180.4–181.3	*p*-$NH_2C_6H_4COCH_3$	177.8–179.3
o-$ClC_6H_4NH_2$	192.9–193.6	1-$C_{10}H_7NH_2$	248.4–249.9
m-$ClC_6H_4NH_2$	209.8–210.3	2-$C_{10}H_7NH_2$	217.3–219.1
p-$ClC_5H_4NH_2$	213–231	*o*-$C_6H_5C_6H_4NH_2$	194.1–195.6
o-$BrC_6H_4NH_2$	206.1–206.6	*p*-$C_6H_5C_6H_4NH_2$	253.8–254.9
m-$BrC_6H_4NH_2$	204.1–205	$C_6H_5CH_2NH_2$	184.5–185.5
p-$BrC_6H_4NH_2$	214–234	$(C_6H_5CH_2)_2NH$	158.3–159.3
o-$NO_2C_6H_4NH_2$	Oil	$(C_6H_5CH_2)_3N$	205.2–207.7
m-$NO_2C_6H_4NH_2$	213.5–215	$C_6H_5NHCH_2C_6H_5$	148.3–148.8
p-$NO_2C_6H_4NH_2$	232.2–234.7	$C_6H_5N(CH_2C_6H_5)_2$	Oil
o-$HOC_6H_4NH_2$	224.7–226.2	*o*-$C_6H_4(NH_2)_2$	267.3–268.8
m-$HOC_6H_4NH_2$	Oil	*m*-$C_5H_4(NH_2)_2$	296.8–297.8
p-$HOC_6H_4NH_2$	252.1–253.6	1,2,4-$CH_3C_6H_3(NH_2)_2$	270.8–271.3

The amine salts of 1- and 2-naphthalenesulfonic acid [31] are also only slightly soluble in cold water, the most soluble being the aniline salt which dissolves to the extent of 1.58 g./100 g. solution at 15°.

Numerous arylammonium salts have also been prepared from naphthalene-2,6-, 2,7-, 1,5-, and 1,6-disulfonic acids.[32] A method for separating various naphtholsulfonic acids has been devised,[33] based on the observation that if enough arylamine is added to a solution to precipitate the 2-naphthol-6-sulfonic acid (Schäffer's acid) or 2-naphthol-3,6-disulfonic acid (R acid) which may be present, the 2-naphthol-6,8-disulfonic (G acid) and 2-naphthol-8-sulfonic acid (crocein acid) are left in solution. Arylammonium salts of other naphtholsulfonic acids were also prepared.[34] It was not possible to obtain salts of naphthionic acid (1-aminonaphthalene-4-sulfonic acid), but they were prepared for the N-acetyl compound. This is also true for other aminonaphthalenesulfonic acids.[35]

The low solubility of the aniline salts of the anthraquinonesulfonic acids makes them of possible value in analytical determination of the acids.[36] For details of the preparation and properties of the anthraquinonesulfonates the original should be consulted.

B. HYDROLYSIS, REDUCTION, AND OXIDATION REACTIONS OF SULFONIC ACIDS

The conversion of sulfonic acids into various salts has been described in the preceding section and the methods for preparing sulfonyl halides are covered in the chapter on sulfonic acid derivatives. Reactions in which the sulfo group undergoes replacement by hydrogen, halogen, hydroxyl, and other groups are considered here. The effect of the sulfo group on the behavior of other substituents attached to the aromatic nucleus is also outlined.

In the cleavage of the carbon-sulfur linkage that occurs when sulfonic acids are fused with alkali or heated with a salt the electron pair is retained by the sulfur, giving rise to a sulfite. In acid solution on the other hand the carbon atom retains the pair of electrons and sulfuric acid is formed. The action of a hypohalous acid likewise gives the halobenzene and sulfuric acid—never phenol and the halosulfonic acid.

Replacement by Hydrogen; Acid Hydrolysis

It was early observed that the sulfonation of aromatic compounds is a reversible process; heating a sulfonic acid in acid solution, or even with water alone, results in the formation of sulfuric acid and the original unsulfonated compound.[37] It should be added that the presence of an inorganic acid in the aqueous solution not only serves to raise the boiling point of the mixture but also greatly accelerates the rate of hydrolysis. This is particularly evident in the behavior of durene- and pentamethylbenzenesulfonic acids[38] which partially hydrolyze even at room temperature when shaken with 95% sulfuric acid. Here the equilibrium between the hydrocarbon and the acid favors the hydrocarbon sufficiently for the hydrolysis to become evident when only a small amount of water is present, provided that acid is available to catalyze the reaction.

Crafts[39a] has reported on a comprehensive investigation of the hydrolysis of various alkyl, halo, and amino sulfonic acids by sulfuric and the halogen acids for a number of concentrations and temperatures. For each rise in temperature of 10° the reaction velocity of hydrolysis increases from 2.5 to 3.5 times, and interestingly enough, a similar increase was observed at any given temperature for an increase of one molar in the concentration of the mineral acid in the solution. The equation

$$(C + \log_e C) + \beta = \log_{10} K$$

expresses the relationship between the rate of hydrolysis (K) and the concentration (C) of the mineral acid. The rate of hydrolysis in concentrated acid solutions was thus found to be several hundred times as great as might be expected from the effect of the acid in dilute solutions providing the rate were proportional to the concentration. This behavior does not apply, however, to the amino derivatives. The hydrolysis rate for these increases only slightly or in some instances decreases with increase in acid concentration.

The temperature at which concentrated phosphoric acid[39b] brings about hydrolysis of a variety of sulfonic acids has been reported. The data are summarized in Table III. Nitrobenzenesulfonic acids did not decompose in phosphoric acid solution.

TABLE III

HYDROLYSIS OF SULFONIC ACIDS

Aryl Group of Sulfonic Acid	Decomposition Temperature, °C.
C_6H_5-	227
o-$CH_3C_6H_4$-	188
m-$CH_3C_6H_4$-	155
p-$CH_3C_6H_4$-	186
2,4-$(CH_3)_2C_6H_3$-	137
3,4-$(CH_3)_2C_6H_3$-	175
m-$C_6H_4(COOH)$-	160
m-ClC_6H_4-	182
4-ClC_6H_4-	200
4-BrC_6H_4-	217
2,4-$Cl_2C_6H_3$-	155
α-$(CH_2)_4C_6H_3$-	135
β-$(CH_2)_4C_6H_3$-	152
2-$CH_3C_{10}H_6$-3-	129
4-$BrC_{10}H_6$-1-	132

Alkyl- and Halobenzenesulfonic Acids. According to Armstrong and Miller[37c] the presence of methyl *ortho* or *para* to the sulfonic acid group facilitates hydrolysis but has little effect when it is *meta*. (However, see Table III.) Bromine, on the other hand, slows the reaction. As an extreme case a comparison of mesitylene- and tribromobenzenesulfonic acids is interesting. The former is hydrolyzed some 14,000 times as rapidly as the latter. Mesitylenesulfonic acid is almost completely hydrolyzed by 38% hydrochloric acid[39a] in 15 minutes at 80°. Hydrolysis has even been effected by boiling with 50% acetic acid.[40] 2,4,6-Triethylbenzenesulfonic acid decomposes to give triethylbenzene when heated alone or even when crystallized from alcohol.[41] On the other hand, various di, tri, and tetrabromobenzenesulfonic acids hydrolyze[37g,h,42] only when treated with concentrated hydrochloric or hydrobromic acid at temperatures ranging from 150° to 250°. 2,5-Dibromobenzenesulfonic acid is unaffected by water at 220° and 3,5-dinitro-4-bromobenzenesulfonic acid[43] is unchanged by refluxing with 60% sulfuric acid. However, the completely substituted compound 3,5-dinitro-2,4,6-tribromobenzenesulfonic acid[42] is hydrolyzed by heating in water solution at 230°.

The separation of the isomeric xylenes by taking advantage of the difference in the rates at which their sulfonic acids hydrolyze has been studied carefully.[44] Adding water to the mixture of sulfonic acids and distilling gives the *m*-xylene at 125–155° while at 155–200° a mixture of the other two isomers comes over. The *o*-xylene-4-sulfonic acid hydrolyzes somewhat less readily than does the *p*-xylene compound. The *o*-xylene-3-sulfonic acid changes to the 4-isomer when hydrolysis is attempted.

It is interesting to note that the sulfonic acids from octahydroanthracene and octahydrophenanthrene, which may be considered analogous to tetraalkylbenzenesulfonic acids, differ markedly in their ease of hydrolysis. The anthracene derivative hydrolyzes readily when treated with hydrochloric acid while the phenanthrene compound requires more drastic conditions.[45] It is probable that this difference likewise exists between isomeric tetraalkylbenzenesulfonic acids.

In the hydrolysis of a series of substituted benzenesulfonanilides Schreiber and Shriner[46] found that those derived from *m*-xylene- and mesitylenesulfonic acids not only split to give the amine and sulfonic acid but also the sulfonic acid underwent conversion to the hydrocarbon. Here the hydrolytic agent was 25% hydrochloric acid. The yield of mesitylene was about 90% whereas only about 10% of the *m*-xylene was recovered. Benzene-, *p*-toluene-, *o*-nitrobenzene-, and *p*-nitrobenzenesulfonic acids were stable under these conditions. It was mentioned[39b] earlier that phosphoric acid has been employed in the hydrolysis of several sulfonic acids[47] with satisfactory results. Although its catalytic effect is not so great as that of sulfuric acid the loss of material through side reactions is less because the phosphoric acid does not have the oxidizing action of sulfuric acid.[37e]

Naphthalenesulfonic Acids. When a mixture of the 1- and 2-naphthalenesulfonic acids is treated with steam at 160° the 1-isomer is hydrolyzed [48] to naphthalene leaving the pure 2-sulfonic acid, a process of commercial importance in the preparation of pure 2-naphthol.

This difference in ease of hydrolysis was also noted [48a] when the acids were heated with dilute hydrochloric acid at 200°. From these observations it might be expected that naphthalene-1,6-disulfonic acid [49] would hydrolyze in stages, but this is apparently not true as no evidence for even a trace of a monosulfonic acid could be found in the reaction mixture. It may be suggested that the acid remaining from the first step in the reaction is activated sufficiently to bring about the loss of the second sulfo group immediately. Naphthalene formation became noticeable with 64% sulfuric acid at 120° and in a 1% solution at 180°. With 73% sulfuric acid at 160° the 2,6- and 2,7-disulfonic acids made their appearance. Similar results were obtained with naphthalene-1,5-disulfonic acid [50] except that hydrolysis became noticeable at a slightly lower temperature with the more dilute sulfuric acid solutions.

A variety of dimethyl- [51] and dichloronaphthalenesulfonic [52] acids have been hydrolyzed in acid solutions at a high temperature. Of these only 1,8-dichloronaphthalene-3-sulfonic acid offered unusual difficulty, the yield of dichloronaphthalene being small.

Phenol and Naphtholsulfonic Acids. Phenolsulfonic acids undergo acid hydrolysis readily when the hydroxyl is located *ortho* or *para* to the sulfo group. Phenol-*o*-sulfonic acid is nearly completely hydrolyzed by concentrated hydrochloric acid [53] at 100° in 9 hours while the *para* isomer is split to the extent of about 40% in 7 hours.[54] 2-Halophenolsulfonic acids are likewise easily hydrolyzed, a reaction utilized in the synthesis of the *o*-halophenols.[55] Bruckner [56] found that the temperatures required for the hydrolysis of phenolsulfonic acids varied enough so that a mixture of coal-tar phenols could be partially separated by sulfonation and gradated hydrolysis. The temperatures in Table IV indicate the boiling points of the dilute sulfuric acid solutions necessary for cleavage to occur.

The conversion of catechol mono and disulfonic acids [57] into catechol, and of pyrogallol-4-sulfonic acid into pyrogallol by acid hydrolysis has been mentioned in the patent literature.[58] Hydroquinonetetrasulfonic acid hydrogen sulfate by heating with water or acid reverts to a disulfonic acid.[59]

2-Naphthol-1-sulfonic acid hydrolyzes even more easily than a sulfonated phenol.[60] 1-Naphthol-2,4-disulfonic acid when warmed with hydrochloric acid [61] yields a mixture of the 2- and 4-monosulfonic

TABLE IV

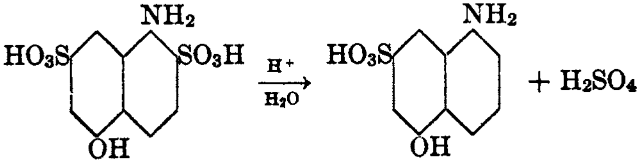
HYDROLYSIS OF PHENOLSULFONIC ACIDS

Sulfonic Acid	Temperature, °C.
Phenol-4-	123–125
2-Methylphenol-4-	133–135
3-Methylphenol-4-	116–119
4-Methylphenol-2-	133–136
2,3-Dimethylphenol-4-	115–118
3,4-Dimethylphenol-6-	107–111
2,6-Dimethylphenol-4-	124–128
2,5-Dimethylphenol-4-	114–118
2,4-Dimethylphenol-6-	121–125

acids. It is interesting to note that 1-hydroxy-4,7-disulfo-2-naphthoic acid [62] with dilute sulfuric acid loses the 4-sulfo group while with 3% hydrochloric acid, carbon dioxide is eliminated. 1-Hydroxy-4-sulfo-2-naphthoic acid is rapidly converted into 1-naphthol with dilute sulfuric acid.[63]

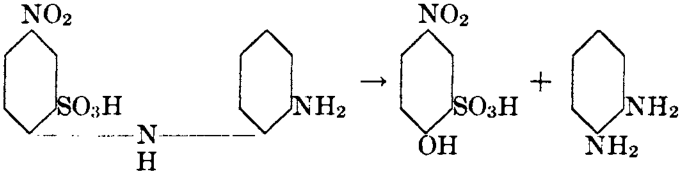
Removal of the sulfonic acid groups from a variety of other naphthol- [64] and dihydroxynaphthalenesulfonic acids [64b, 65] has been reported.

Aniline and Naphthylaminesulfonic Acids. The unusual behavior of aminosulfonic acids in solutions of increasing acid concentration [59a] has been mentioned in the first part of this section. As might be expected from this, 4-methylaniline-2,6-disulfonic acid [66] when heated with water at 140° loses only one of the sulfo groups as do certain aminonaphthalenedisulfonic acids,[67] and aminonaphthalenetrisulfonic acids.[67a, 68] It is sometimes possible, however, to obtain the unsulfonated amine. Naphthionic acid is quickly hydrolyzed to 1-naphthylamine [69] when heated with a solution made from two volumes of sulfuric acid to one of water at 180°. 1-Aminonaphthalene-3,8-disulfonic acid [70] when heated with water gives ammonia and the naphthol. Dilute acid removes the 8-sulfo group and then ammonia is eliminated, producing 1-naphthol-3-sulfonic acid. The 1-amino-4,6,8-trisulfonic acid in similar manner yields the naphthol-6,8-disulfonic acid.[71] Another variation of this reaction is seen in the behavior of 1,5-aminonaphthol-2,7-disulfonic acid [72] which loses one sulfo group.



3-Amino-2-naphthol-7-sulfonic acid at 180–200° in acid solution[73] loses both the sulfo and amino groups giving 2,3-dihydroxynaphthalene. Other aminonaphtholsulfonic acids behave similarly.[65b, 67c, 74a]

Hydrolysis of 2′-amino-4-nitrodiphenylamine-2-sulfonic acid with 70% sulfuric acid produces *o*-phenylenediamine and the nitrophenolsulfonic acid[74b] as well as some normal hydrolysis product.



Anthracene and Anthraquinonesulfonic Acids. Heating sodium anthracene-2,9,10-trisulfonate with 20% hydrochloric acid removes the 9- and 10-sulfo groups.[75c] A sulfo substituent attached to either the 1- or 2-position of the anthraquinone nucleus is hydrolyzed when the compound is heated with about 50% sulfuric acid[75a] at 190–200° in the presence of a mercury salt. 8-Nitroanthraquinone-1-sulfonic acid[75b] goes to nitroanthraquinone under this treatment despite the fact that other reagents replace the nitro group first. A disulfonic acid such as the anthraquinone-2,6-disulfonic acid may be hydrolyzed, by regulating the reaction conditions, to the more useful 2-sulfonic acid.[76] Hydroxyanthraquinonesulfonic acids in which the hydroxyl is *ortho* or *para* to the acid group hydrolyze under less severe reaction conditions than those required for the foregoing compounds,[77] and hence when two sulfo groups are present, one in an hydroxylated and the other in an otherwise unsubstituted nucleus, the former is removed preferentially.[78] In this connection the behavior of the isomeric sulfonic acids derived from 1,2,4-trihydroxyanthraquinone (purpurin) is interesting. The 3-acid is hydrolyzed with dilute hydrochloric acid by heating under pressure[79] while the 8-compound requires the action of sulfuric acid in the presence of a mercuric salt and boric acid at 190°. As might be expected, the 6- or 7-isomer is not affected by boiling dilute mineral acids.[80] When the 3,8-disulfonic acid is heated with 70% sulfuric acid at 180° the 3-sulfo group is lost, whereas if mercuric sulfate is added purpurin is the final product.[81] An interesting modification of these hydrolysis reactions is that described by Marschalk.[82] The leuco compounds derived from dyes, such as quinizarin-2-sulfonic acid, by warming in water or an alkali salt solution in the absence of air are converted into the unsulfonated hydroxyanthraquinones with liberation of sulfurous acid.

Fieser[83] has reported that when 1,2-anthraquinone-4-sulfonic acid is heated with methyl-alcoholic sulfuric acid an 85% yield of the 4-methoxy compound results. Undoubtedly other similar compounds may show this anomalous behavior in acid solution.

Sulfonic Acids from Heterocyclic Compounds. It has been claimed in the patent literature that several complex carbazolesulfonic acids[84] hydrolyze in dilute acid or water solutions at a high temperature under pressure.

REPLACEMENT BY HYDROGEN; ACTION OF REDUCING AGENTS

Since halogen derivatives of benzene and alkylbenzenesulfonic acids can be dehalogenated by sodium amalgam and other reducing agents, it is evident that the sulfonic acid group is relatively inert against reduction when it is attached to a benzene nucleus. Apparently the only procedure capable of reducing benzenesulfonic acid to benzene and sulfite is electrolysis with a high current density in a strongly alkaline solution.[85] Sulfanilic acid and *p*-phenolsulfonic acid under the same conditions show no change. The three sulfobenzoic acids are reduced, as is metanilic acid.

The behavior of naphthalenesulfonic acids is quite different.[48c, 86] In a slightly acidic medium all α-naphthalenesulfonic acids are readily reduced by sodium amalgam, the sulfo group being replaced by hydrogen and converted into sulfur dioxide, whereas the β-sulfonic acids are only slowly affected at a much higher temperature. This distinction also holds in electrolytic reduction of the two types of acid. This difference has proved useful in determining the structure of complex sulfonation products of naphthalene and its derivatives and also commercially in the synthesis of naphthalene derivatives otherwise difficult to obtain.[87] It is even possible to remove a sulfo group and leave a chlorine intact,[88] thus reversing the behavior of halobenzenesulfonic acids. Since the two isomeric acenaphthenedisulfonic acids[89] obtained by sulfonating the hydrocarbon each lose one sulfo group when treated with sodium amalgam it is probable that the lost groups occupy alpha positions in the nucleus.

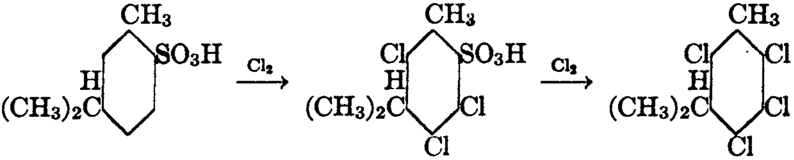
Electrolytic reduction[85] is effective in removing the sulfo group from 1-naphthylamine-4- and 5-sulfonic acids but not from the 1,6-, 1,7-, and 2,6-compounds. The 1,4- and 1,5-naphtholsulfonic acids reduce slowly while the 1,2- and 2,6-isomers are unaffected.

In certain derivatives of the anthraquinonesulfonic acids sulfo groups may be eliminated by a variety of reducing agents. Anthraquinone-2-sulfonic acid is reduced by sodium amalgam or zinc to the anthracenesulfonic acid[90] and sulfonated anthraquinonecarboxylic acids[91] are likewise converted to anthracene derivatives by zinc and alkali while tin in a mixture of hydrochloric and acetic acids[92] reduces anthraquinone-1-sulfonic acid, the disulfonic acids, and hydroxysulfonic acids to anthranolsulfonic acids. On the other hand, numerous hydroxy- and aminoanthraquinonesulfonic acids lose the sulfo group when treated with zinc in acid solution,[93] or more commonly, with sodium hydrosulfite in alkaline solution.[94] Because of the broad claims of the patents it is difficult to draw conclusions as to the effect of various substituents upon the ease of elimination of a sulfo group but it is obvious that an *ortho* or *para* hydroxyl group facilitates the reaction.

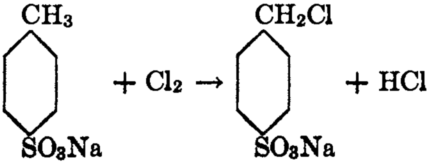
HALOGENATION OF SULFONIC ACIDS

Chlorination of Aromatic Sulfonic Acids. In the halogenation of sulfonic acids several reactions may occur, depending upon the experimental conditions and the various groups that are attached to the aromatic nucleus. The chlorination of sulfonic acids has not been studied as extensively as bromination which will be taken up in the next section.

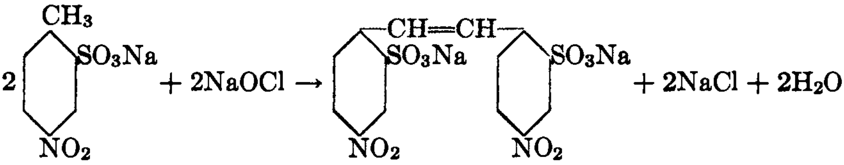
Chlorination in aqueous solution usually leads to replacement of the sulfo group although this may not be the first step in the reaction. *p*-Bromobenzenesulfonic acid with chlorine in warm water[95] gives *p*-chlorobromobenzene, *p*-xylenesulfonic acid yields 2,5-dichloro-*p*-xylene, mesitylenesulfonic acid is converted into the trichloromesitylene,[95] and *m*-cymenesulfonic acid is first trichlorinated followed by replacement of the sulfo group.[96]



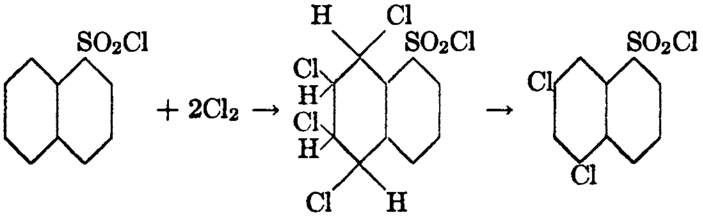
p-Toluenesulfonic acid with chlorine water or potassium chlorate and hydrochloric acid[97] gives the 4-methyl-3-chlorosulfonic acid, whereas with dry chlorine at 120–140° the side chain reacts.[98]



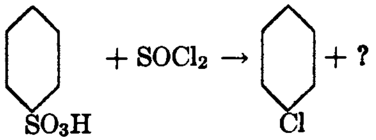
If a nitro group is *para* to the methyl as in *p*-nitrotoluene-*o*-sulfonic acid, aqueous sodium hypochlorite causes oxidation with junction of the side-chain carbons[99] to give a dibenzyl or a stilbene derivative.



Chlorination of 1-naphthalenesulfonic acid with sodium chlorate and hydrochloric acid[100] has been reported to give chiefly the 5-chlorosulfonic acid while the 2-isomer substitutes in the 5- and 8-positions.[101a] However, in boiling dilute hydrochloric acid, potassium chlorate has more recently[101b] been found to give a mixture of dichloronaphthalenes with both sulfonates. The 1,6-dichloronaphthalene is the chief product from the 1-sulfonic acid and the 2-acid gives about 50% of the 2,6-compound. The dichlorination does not occur at 50–60°. The naphthalenesulfonyl chlorides with chlorine in carbon disulfide give addition products, the unsubstituted ring reacting.[102a] By treating the addition compound with alkali the 5,7-dichloronaphthalenesulfonic acid results.

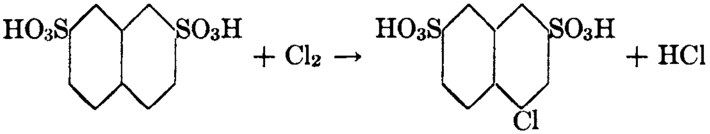


It has been shown by Meyer[102b] that the action of thionyl chloride at a high temperature upon sulfonic acids or their salts replaces the sulfo group by chlorine.

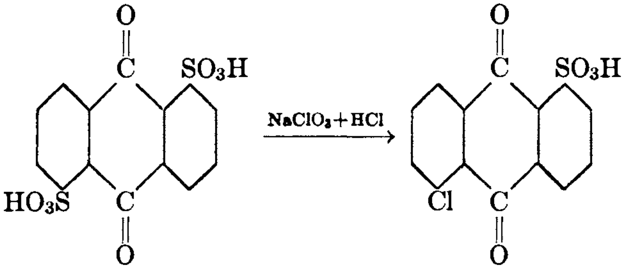


Recently[102c] numerous sulfonic acids have been found to undergo reaction with cupric chloride when heated with this salt to a high temperature in a copper flask with replacement of the sulfo group with chlorine. The yield of halogen compound is not high. Best results reported were for *m*-xylenesulfonic acid which gave 9 g. of chloroxylene from 25 g. of acid and an equal weight of cupric chloride.

4-Bromonaphthalene-1-sulfonic acid with chlorine gives 1-chloro-4-bromonaphthalene.[103] Various nitronaphthalene-α-sulfonic acids react with chlorine or chlorinating agents [104] to yield the corresponding nitrochloronaphthalenes. Naphthalene-2,7-disulfonic acid reacts only by substitution.



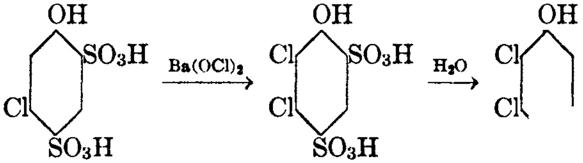
Chlorination of anthraquinone-1-sulfonic acid [105] in oleum solution gives the 5,8-dichloro compound but under other conditions the sulfo group is replaced, regardless of whether this occupies the alpha or beta position. The chlorinating agent most frequently employed has been an alkali chlorate and hydrochloric acid.[106] By the use of the proper amount of sodium chlorate and hydrochloric acid either one or both of the sulfo groups of anthraquinonedisulfonic acids may be replaced with chlorine.[107]



The sulfo groups of the 2-methylanthraquinone-4-sulfonic acid and -1,4-disulfonic acid are also readily replaced by chlorine when boiled with aqueous potassium chlorate and hydrochloric acid.[108]

Compounds in which the sulfo group is *ortho* or *para* to hydroxyl are chlorinated readily to give sulfur-free compounds. The mono, di, and trisulfonation products of phenol all yield 2,4,6-trichlorophenol [109] although the yield is small for the trisulfonic acid. Somewhat similar results were obtained with sulfonic acids derived from the cresols, thymol, carvacrol, and *p*-xylenol,[95] and *o*- and *p*-nitrophenol.[109] In these chlorinations an indefinite amount of chlorine was used so it is difficult to evaluate the results.

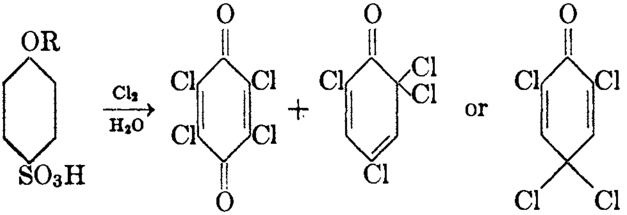
Other investigators have shown that phenol-*p*-sulfonic acid may be treated with chlorine [110] or potassium chlorate and hydrochloric acid [111] without replacing the sulfo group. A more satisfactory method is to carry out the chlorination in nitrobenzene solution,[112a] hydrolysis of the resulting chlorinated sulfonic acids giving a 70% yield of 2,6-dichlorophenol and 17% of 2-chlorophenol. 3-Chlorophenol-6-sulfonic acid is converted by barium hypochlorite into the 2,3,4-trichloro compound without removing the sulfo group.[112b,116] The 4,6-disulfonic acid similarly yields the 2,3-dichloro compound.



Chlorination of *m*-cresoldisulfonic acid in fuming sulfuric acid[113] followed by hydrolysis gives 2-chloro-*m*-cresol indicating that the sulfo groups are not affected under these conditions. The *ortho* and *meta* cresolsulfonic acids may also be chlorinated in nitrobenzene solution.[112a]

2-Nitrophenol-4-sulfonic acid with chlorine in alcohol solution yields the 6-chloro compound[114] while with excess chlorine 4,6-dichloro-2-nitrophenol results.[115] 2-Methylphenol-4-sulfonic acid behaves analogously.[116]

The exhaustive chlorination of anisole- and phenetolesulfonic acids[109] gives a mixture of tetrachloroquinone (chloranil) and a tetrachloroketodihydrobenzene.



It was assumed that trichlorophenol is an intermediate in the reactions.

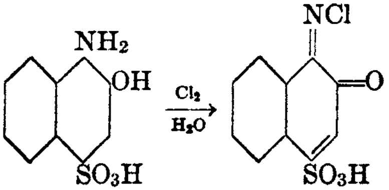
Catechol-4-sulfonic acid yields tetrachloro-*o*-quinone,[95] and orcinoldisulfonic acid, a pentachloro compound.[109] Hydroquinonesulfonic acid gives the tetrachloroquinone.[95]

Sulfonic acids derived from *o*-, *m*-, and *p*-hydroxybenzoic acids when treated with chlorine lose the sulfo but not the carboxy groups.[109]

The action of aqueous sodium hypochlorite upon *p*-cresoldisulfonic acid[117] gives as a final product a lactone believed to belong to the sugar group since upon concentration of the aqueous solution an odor of caramel developed. A structure for the compound was proposed but the evidence for it is incomplete.

The chlorination of various polyhydroxyanthraquinonesulfonic acids[118] results in replacement of the sulfo groups as in the benzene series.

Aminosulfonic acids react with chlorine very much as do the hydroxy compounds. Metanilic acid is converted into chloranil by passing a stream of chlorine through an aqueous solution of the acid[119] while *ortho* and *p*-nitranilinesulfonic acids[109] yield dichloronitranilines. 1-Aminoanthraquinone-2-sulfonic acid reacts without loss of the sulfo group,[120] the 4-chloro compound resulting. The chlorination of 1-amino-2-hydroxynaphthalene-4-sulfonic acid[121a] produces a chloroimine. Best yields were obtained in a solution of potassium acetate.



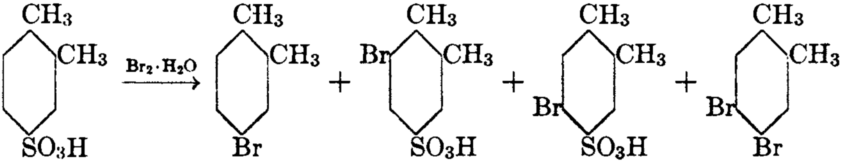
Sulfur dioxide reduces the chloroimine to the original sulfonic acid. Chloroimines were also obtained without loss of the sulfo group from the 1-hydroxy-2-amino-4-sulfonic acid and the 1,4-diamino-6-sulfonic acid. 2-Acetaminonaphthalene-6-sulfonic acid chlorinates in the 1-position without replacement of the sulfo group.[121b]

Bromination of Sulfonic Acids. A great many sulfonic acids have been brominated, practically all the reactions having been carried out in aqueous solution. Depending upon the substituents present in the aromatic ring there results either a bromosulfonic acid, an aryl bromide from which the sulfo group has been eliminated, or a mixture of both types. The presence of a hydroxy or amino group *ortho* or *para* to the sulfo group favors its replacement with bromine. Replacement also occurs readily with the polyalkylbenzene derivatives.

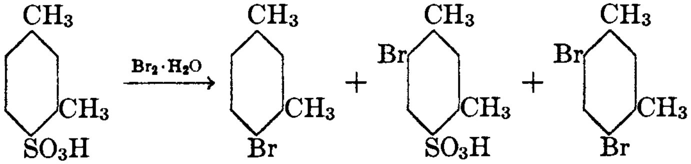
Heating benzenesulfonic acid with bromine and water in a sealed tube[122] to 150° gives chiefly *m*-bromobenzenesulfonic acid together with some bromobenzene and sulfuric acid. It is uncertain whether the bromobenzene arises from replacement of the sulfo group, hydrolysis of the *m*-bromobenzenesulfonic acid, or bromination of benzene (from hydrolysis of benzenesulfonic acid). At 100° or lower no bromobenzene was noted.[95,123] The action of bromine upon an aqueous solution of silver benzenesulfonate[124,125] gives *m*-bromobenzenesulfonic acid readily. Silver *m*-bromobenzenesulfonate in turn yields a mixture of the 3,4- and 3,6-dibromobenzenesulfonic acids. The 3,4-acid also results from silver *p*-bromobenzenesulfonate and bromine.[126] The 3,4-dibromosulfonate in turn gives a small amount of a tribromobenzenesulfonic acid, probably the 3,4,5-compound. The action of excess bromine upon *p*-bromobenzenesulfonic acid in water gives 1,2,4,5-tetrabromobenzene, the sulfo group being replaced.[95] *p*-Iodobenzenesulfonic acid was reported to not react with bromine.

p-Toluenesulfonic acid after four days standing with bromine water gives a 40% yield of 2,4,5-tribromotoluene.[95] The reaction with one mole of bromine has apparently not been studied. The statement has been made[95] that ethylbenzenesulfonic acid does not react with bromine.

When 1,2-dimethylbenzene-4-sulfonic acid[127] is treated with bromine water there results a number of products as shown below.



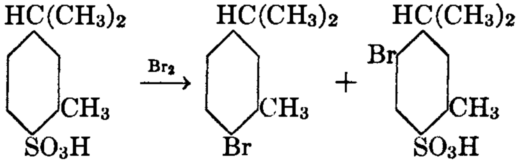
m-Xylene-4-sulfonic acid behaves similarly.[127a,128] With a large ex-



cess of bromine the tetrabromo-*m*-xylene is formed,[95] undoubtedly by further bromination of the 4,6-dibromo compound. A small amount of the 4,6-dibromo-*m*-xylene also results by the action of bromine upon the corresponding disulfonic acid.[129] This reaction was used to prove the structure of the acid.

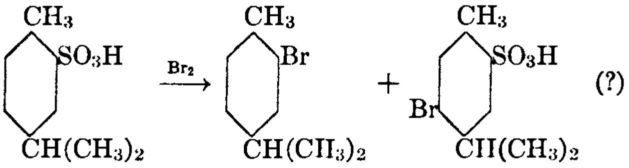
p-Xylenesulfonic acid behaves similarly to the other xylene derivatives. With an excess of bromine water "more than a 50% yield" of 2,5-dibromo-*p*-xylene was isolated.[95]

Bromination of *m*-cymenesulfonic acid in hydrobromic acid at 40° gives a mixture of two compounds as shown. From 175 g. of the barium sulfonate there results 62 g. of the crude bromo-*m*-cymene containing a little dibromo compound.[130] The structure of the bromo-



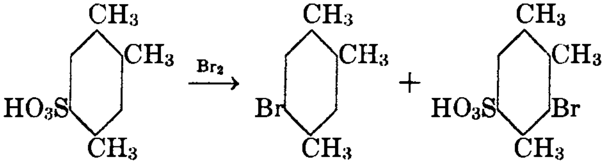
sulfonic acid is probable but not proved. When treated with bromine water it is converted into the corresponding dibromo-*m*-cymene.[180c]

p-Cymenesulfonic acid behaves similarly except that a higher yield of the bromo-*p*-cymene is obtained.[180b, 181] The structure of the bromo-



sulfonic acid is questionable. *m*-Butyltoluenesulfonic acid reacts with bromine analogously to *m*-cymene.[182]

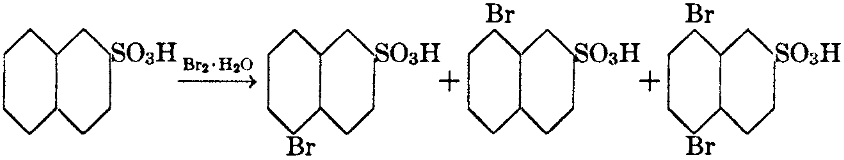
Several trialkylbenzenesulfonic acids have been brominated. 1,2,4-Trimethylbenzene-5-sulfonic acid when heated with bromine water on the steam bath [133] gives a 76% yield of the bromopseudocumene.



The 6-sulfonic acid similarly gives the 6-bromo compound. Mesitylenesulfonic acid with one mole of aqueous bromine [134] gives a mixture of bromomesitylene and bromomesitylenesulfonic acid. With an excess of bromine 2,4,6-tribromomesitylene results.[95] Mesitylenedisulfonic acid is reported [135] to give dibromomesitylene while the trisulfonic acid does not react with bromine. Bromination of sodium 1,3-dimethyl-5-ethylbenzene-2-sulfonate in hydrochloric acid [136] gives the 4-bromo sulfonic acid. 1,3,5-Trimethyl-2-*n*-propylbenzene-4-sulfonic acid yields the 4,6-dibrominated hydrocarbon.[187] Octhracene-(octahydroanthracene)-9-sulfonic acid reacts readily with bromine [188] in acid solution with replacement of the sulfo group while in acetic acid the 9,10-dibromo compound results. Treating an aqueous solution containing a mixture of biphenyl-4-sulfonic acid and 4,4′-disulfonic acid [95] with bromine gives a 13% yield of 4,4′-dibromobiphenyl.

The remark that sulfonic acids of dibenzyl and triphenylmethane do not react with bromine[95] would seem to require further investigation.

The behavior of the naphthalenesulfonic acids toward bromine varies with the position of the sulfo group. α-Naphthalenesulfonic acid when brominated in aqueous solution gives a mixture of 1,4- and 1,5-dibromonaphthalenes, and 5-bromonaphthalenesulfonic acid.[139, 140] The statement has also been made[109] that bromination yields naphthalene, 1,5-dibromonaphthalene, and 1,7-dibromonaphthalene but no experimental details were given. β-Naphthalenesulfonic acid yields a mixture of sulfonic acids[140, 141] as shown below. The structure of the dibromosulfonic acid is uncertain. Naphthalene-1,5-disulfonic acid gives a dibromosulfonic acid[142] as does the 1,6-compound.[143] Bromination of 4-chloro- or 4-bromonaphthalene-1-sulfonic acid results in replacement of the sulfo group.[144]



Replacement of the sulfo groups of the anthraquinonesulfonic acids with bromine apparently requires vigorous reaction conditions. Thus heating anthraquinone-1,5-disulfonic acid to 240° with bromine and water in a sealed tube for 24 hours gives a quantitative yield of 1,5-dibromoanthraquinone while at 200° for 20 hours only 30% of this product results, the remainder being 1-bromoanthraquinone-5-sulfonic acid.[107] Bromination of the 1,8-disulfonic acid, 1-chloroanthraquinone-5-sulfonic acid, and the 8-sulfonic acid yields in each case the corresponding bromine compounds in yields of 80%, 63%, and 36% respectively. The 1,6-dibromoanthraquinone was obtained in 10% yield from the disulfonic acid by bromination at 220° for 30 hours.

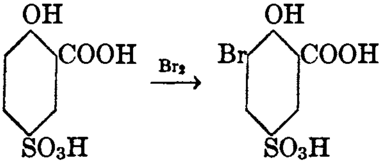
Phenanthrene-3-sulfonic acid brominates readily in aqueous solution, the bromine entering the 9- or 10-position. The statement that retenesulfonic acids do not brominate[95] was accompanied by no experimental data.

Although sulfonic acid groups are easily displaced by bromine when *ortho* or *para* to hydroxyl it is possible to brominate such compounds without displacement occurring. This has been demonstrated for phenol-*o*-[145b] and *p*-sulfonic[145a, 146] acids, nitrophenolsulfonic acids,[147] and phenol-2,4-disulfonic acid[148] in aqueous solution. Here bromine replaces the *para* sulfo group before the *ortho*. This is in contrast with the behavior of 2-nitrophenol-4,6-disulfonic acid[149] which first yields the 6-bromo compound. By the action of excess bromine, phenolsulfonic acids[95,148,150] and nitrophenolsulfonic acids[95,149] lose all the sulfo groups *ortho* and *para* to hydroxyl. Phenol-*p*-sulfonic acid substitutes only in the *ortho* position if treated with bromine in an anhydrous solvent, nitrobenzene[112a] being the most satisfactory medium.

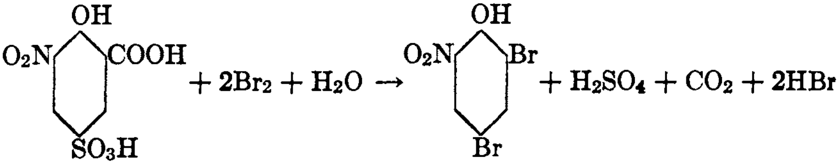
Phenol-*m*-sulfonic acid brominates to the 2,4,6-tribromo compound[151] without loss of the sulfo group.

The cresolsulfonic acids[95,112a,152] give results entirely analogous to those of phenol. *p*-*tert*-Butylphenol-,[153] thymol-[154] (2-isopropyl-5-methylphenol), and carvacrol-[155] (2-methyl-5-isopropylphenol) sulfonic acids have been converted into bromosulfonic acids and then these have also been completely brominated to the dibromophenols.[95] Similarly, 1,2,4-xylenolsulfonic acid gives the 3,6-dibromoxylenol[95] and that of 1,3,4-xylenol brominates to the 2,5,6-tribromoxylenol.

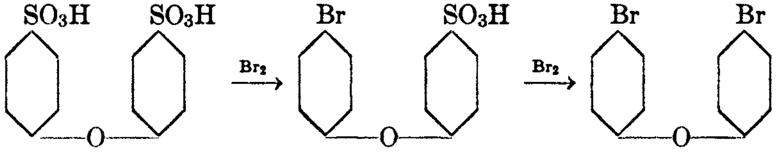
Phenolsulfonic acids containing a carboxyl group may also lose this substituent if excess bromine is added. 5-Sulfo-2-hydroxybenzoic acid reacts with one molecule of bromine[156] as shown in the equation.



With an excess of the halogen tribromophenol is obtained. Sulfo-*p*-hydroxybenzoic acid behaves analogously.[95] A nitrosulfosalicylic acid[149] has also been brominated.

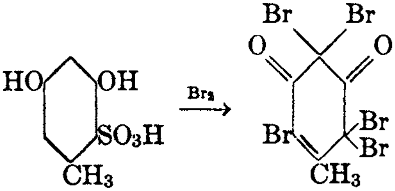


Ethers of phenol-*p*-sulfonic acid for the most part differ from the phenolic compounds in that bromine replaces the sulfo group before substitution in the *ortho* positions takes place. Although *p*-methoxybenzenesulfonic acid, 3-methyl-4-methoxybenzenesulfonic acid[156] and the 2-methyl isomer,[157] and the 2-sulfo-5-methoxybenzoic acid[157] behave in this manner it has been reported[158] that *p*-ethoxybenzenesulfonic acid gives a mixture of 2-bromo-4-sulfo- and 2,4-dibromophenetole. This difference in directive influence of the methoxy and ethoxy groups should be further investigated. Bromination of phenoxybenzene-4-sulfonic acid with one mole of bromine in water[159] gives the 4′-bromo derivative while with a second mole of bromine the sulfo group is displaced. One or both of the sulfo groups in the 4,4′-disulfonic acid may be replaced.



The dihydroxybenzenesulfonic acids are very reactive toward bromine. Catechol-4-sulfonic acid is oxidized,[95] resorcinolsulfonic acid gives 2,4,6-tribromoresorcinol, and hydroquinonesulfonic acid is converted into 2,3,5-tribromohydroquinone.

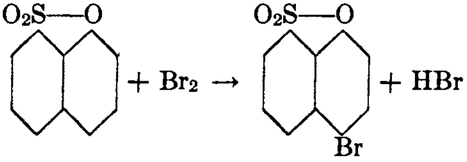
Both of the sulfonic acids obtained from guaiacol upon careful bromination yield dibromo derivatives without loss of the sulfo group.[160] The structures of these compounds have not been ascertained. Orcinolsulfonic acid yields a pentabromo compound[95] and tribromoorcinol.



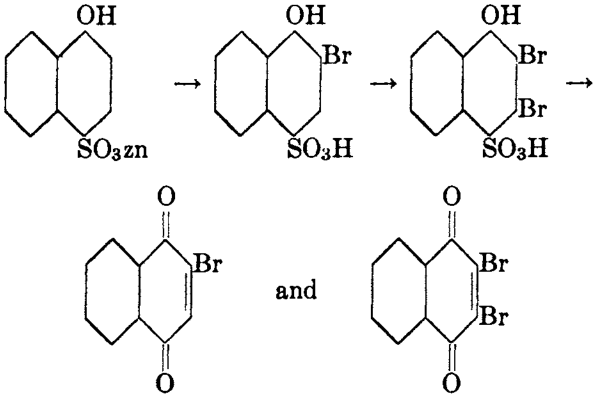
A sulfonic acid derived from 2,4-dihydroxybenzoic acid with bromine yields 2,4,6-tribromoresorcinol; which group is replaced first was not determined.[95]

Bromination of a sulfonic acid obtained from pyrogallol-1,3-dimethyl ether[160] gives either a dibromosulfonic acid or a dibromopyrogallol dimethyl ether, depending upon the temperature. The latter compound is produced at 100°. The structures of these compounds are unknown.

A few naphtholsulfonic acids have been brominated. Where removal of the sulfo group occurs it is accompanied by quinone formation. Naphthosultone with bromine in acetic acid[161] gives the 4-bromo derivative.



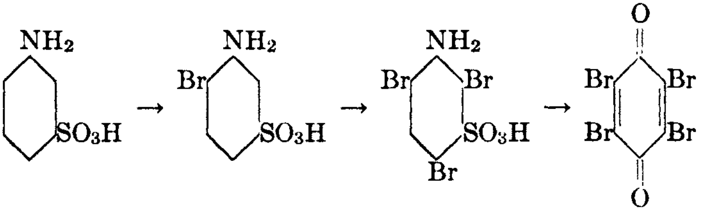
This also results from sodium naphthosultone-4-sulfonate and 1-naphthol-4,8-disulfonate. Excess bromine converts sodium 1-naphthol-8-sulfonate, 1-naphthol-2,4,8-trisulfonate, and the -3,8-disulfonate into 2,3-dibromo-1,4-naphthoquinone-8-sulfonate. The -3,8-disulfonate gives first the 4-bromo derivative. Treatment of zinc 1-naphthol-4-sulfonate with bromine gives the following series of products.



The sulfo derivatives of β-naphthol undergo bromination without quinone formation. The 2-naphthol-1-sulfonic acid has not been investigated, however.

The reaction of bromine in aqueous solution with *o*-aminobenzenesulfonic acid results in the formation of the mono and dibromoaminosulfonic acids and 2,4,6-tribromoaniline, even when only one mole of bromine is used,[162] part of the original acid remaining unbrominated. The addition of a second mole of bromine of course increases the yields of the di- and tribrominated compounds.[163] In the bromination of sulfanilic acid it is possible to introduce two bromine atoms quantitatively without loss of the sulfo group[164] if the reaction mixture is kept at 0°. At 20° or above with excess bromine tribromoaniline is formed in the theoretical amount.[95,165] The results are the same whether a solution of bromine in water, potassium hypobromite, or potassium bromate-bromide with acid is the source of bromine. The reaction has also been carried out in hot glacial acetic acid.[166]

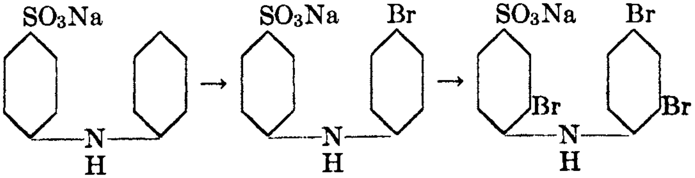
The bromination of metanilic acid proceeds by the steps shown, oxidation occurring as the last stage with formation of bromanil.[167] By carrying out the reaction at room temperature it is possible to stop at the tribromination stage. Aniline-3,5-disulfonic acid gives a dibromo compound of uncertain structure.[168]



Analysis of a mixture of the *ortho, meta,* and *para* anilinesulfonic acids by bromination is easily carried out [164, 169] either by determining the amount of sulfuric acid set free or weighing the tribromoaniline precipitate. If the mixture contains sodium sulfate as an impurity titration of the solution containing the tribromometanilic acid with sodium nitrite after removal of the tribromoaniline is a satisfactory alternative. Bromination of 5-chloroaniline-2-sulfonic acid [147c] gives 2,4,6-tribromo-5-chloroaniline.

Bromination of the sulfonation products from *ortho* and *para* nitroaniline produces the corresponding dibromonitroanilines and from a *m*-nitroanilinesulfonic acid a tribromo compound results as from metanilic acid.[95] A mixture of *m*-toluidine mono and disulfonic acids gives a high yield of tribromo-*m*-toluidine but the sulfonation products of the *ortho* and *para* isomers do not react as satisfactorily, some oxidation occurring when excess bromine water is used. However, it is possible to brominate these compounds readily with bromide-bromate mixture.[170]

Diphenylamine-4-sulfonic acid has not been brominated in aqueous solution so its behavior cannot be compared with that of phenyl ether derivatives. In suspension in carbon tetrachloride the sodium salt gives first the 4′-bromo compound and then a tribromo derivative without loss of the sulfo group.[171] The 4,4′-disulfonic acid first yields the 2,2′-dibromo compound and then 2,2′,4,4′-tetrabromodiphenylamine.



Bromination of 1-naphthylamine-4-, -5-, and -8-sulfonic acids with excess of the halogen gives 2,4-dibromo compounds, the sulfo group being lost in the first instance.[172] On the other hand the 2-naphthylamine-5-, -6-, and -7-sulfonic acids monobrominate in the 1-position. However, the 2-naphthylamine-3,6- and -6,8-disulfonic acids yield dibromo compounds, one sulfo group being lost, quite probably the one in the 6-position. Bromination of a variety of aminonaphtholsulfonic acids always gives rise to naphthoquinone derivatives.

Bromination of 2-methylglyoxaline-5-sulfonic acid in cold water solution gives a small amount of the 4-bromo compound together with decomposition products and unchanged starting material,[173] while glyoxaline-4-sulfonic acid yields a little 2,4,5-tribromoglyoxaline.

Recently [102c] it has been found that low yields of bromo compounds can be made by heating sulfonic acids with cupric bromide to a high temperature. The poorest yield reported was obtained from 2-naphthylamine-6,8-disulfonic acid which gave 1 g. of the 6,8-dibromo-2-naphthylamine from 25 g. of acid.

Iodination of Sulfonic Acids. Iodination of phenolsulfonic acids is readily effected by any one of several procedures but in only one instance has the replacement of a sulfo group by iodine been reported.

Treating phenol-*p*-sulfonic acid in acid solution with potassium iodide and iodate results in the formation of the 2,6-diiodosulfonic acid.[174] Similarly the 2,4-disulfonic acid is converted into the 6-iodo compound.[175] 2-Methylphenol-4-sulfonic acid, 3-methylphenol-4-sulfonic acid and thymol-*p*-sulfonic acid have been iodinated [176] by the same reagents.

Another method of iodination consists in the action of mercuric oxide and iodine, usually in alcohol solution, upon the sulfonic acid derivative. 2-Nitrophenol-4-sulfonic acid [146a] and 4-nitrophenol-2-sulfonic acid [147b] have been iodinated in this manner. In the latter reaction a little 2,6-diiodo-4-nitrophenol was also formed.

Iodine monochloride has been utilized in diiodinating phenol-*o*-sulfonic acid [177] and in the iodination of *p*-cresol-*o*-sulfonic acid and thymol-*p*-sulfonic acid. In hot acetic acid solution 2,6-dibromoaniline-4-sulfonic acid is converted into the 4-iodo compound.[165] The sulfo group in general was found to be more readily replaced than carboxyl.

Nitration of Sulfonic Acids

The nitration of sulfonic acids may lead to displacement of the sulfo group; this is particularly true for phenolsulfonic acids and occurs with other types when nitrogen oxides are used as the nitrating agent.[178] Aside from the occasions where replacement occurs the chief interest in the nitration reactions is in the information they give concerning the directive influence of the sulfo group. These results are best presented in tabular form except for several of the more thoroughly studied reactions.

Nitration of benzenesulfonic acid gives a mixture of the three isomers,[179] the distribution of these being 27% *ortho,* 54% *meta,* and 12% *para.*[180] Separation of these is possible through the iron salts.[181] *m*-Nitrobenzenesulfonic acid with oleum and nitric acid[182] gives 3,5-dinitrobenzenesulfonic acid, and benzene-1,3-disulfonic acid when refluxed with oleum and fuming nitric acid for 8 hours gives a 50% yield of the 5-nitro compound together with some of the 4-isomer.[183]

The products obtained in the nitration of various derivatives of benzenesulfonic acid are shown in Table V.

TABLE V

NITRATION OF BENZENESULFONIC ACID DERIVATIVES

Substituent(s) and Reference(s)	Position(s) of Nitro Group(s)
4-Fluoro-[1]	2-
4-Chloro-[2]	2-
4-Chloro-3-nitro-[3]	5-
2-Chloro-5-nitro-[4]	3-
2,4-Dichloro-[5]	5-
3,4-Dichloro-[6]	6-
2-Bromo-[7]	5- and 3- (trace)
4-Bromo-[8]	3-
3,4-Dibromo-[9]	6-
3,5-Dibromo-[10]	2-
2,4-Dibromo-[11]	5-
2,5-Dibromo-[12]	3- (?)
2,4,6-Tribromo-[11, 13, 14]	3- then 3,5-di-
3,4,5-Tribromo-[10]	2-
2,4,5-Tribromo-[15]	3-
2,3,4,5-Tetrabromo-[15]	6-
2,3,4,6-Tetrabromo-[14]	5-

[1] Holleman, *Rec. trav. chim.*, **24**, 31 (1905).

[2] Fischer, *Ber.*, **24**, 3187 (1891).

[3] Ulmann and Kuhn, *Ann.*, **366**, 102 (1909).

[4] Ulmann and Herre, *Ann.*, **366**, 112 (1909).

[5] Badische Anilin- und Sodafabrik., German pat., 120,345, *Chem. Zentr.*, I, 1127 (1901).

[6] A.-G. für Anilinfabrik, German pat., 175,022, *ibid.*, II, 1536 (1906).

[7] Bahlmann, *Ann.*, **186**, 315 (1877).

[8] Goslich, *Ann.*, **180**, 98 (1876); Fricke, *J. prakt. Chem.*, [2] **8**, 225 (1870).

[9] Goslich, *Ann.*, **186**, 152 (1877).

[10] Lens, *Ann.*, **181**, 32 (1876).

[11] Bässmann, *Ann.*, **191**, 235 (1878).

[12] Borns, *Ann.*, **187**, 358 (1877); Hübner and Williams, *Ann.*, **167**, 121 (1873).

[13] Knuth, *Ann.*, **186**, 296 (1877).

[14] Langfurth, *Ann.*, **191**, 184 (1878).

[15] Spiegelburg. *Ann.*, **197**, 297 (1879).

The action of the nitrogen oxides from arsenic trioxide and nitric acid upon the *p*-chloro, *p*-bromo, and *p*-iodobenzenesulfonic acids leads to the formation of the corresponding nitro compounds by displacement of the sulfo group.[178]

TABLE VI

NITRATION OF DERIVATIVES OF ALKYLBENZENESULFONIC ACIDS

Substituent(s) and Reference(s)	Position(s) of Nitro Group(s)
2-Methyl-[1]	5-, then 3,5-di-
4-Methyl-[1a, 2, 3]	3-, then 3,5-di-
3-Methyl-4-chloro-[4, 5]	5- and 6-
2-Methyl-4-chloro-[5]	5-
4-Methyl-3-chloro-[4]	6-
2-Methyl-5-bromo-[7, 8]	3- (?)
2-Methyl-4-bromo-[9, 10]	5-
3-Methyl-4-bromo-[7, 10]	?
3-Methyl-6-bromo-[7, 8]	?
4-Methyl-3-bromo-[11]	?
3,4-Dimethyl-[12]	2-, 5-, and 6-
2,4-Dimethyl-[13, 14, 15]	3-, 5-, 6- (?), and then 3,5-di-
2,4-Dimethyl-5-nitro-[15b]	6- and 3-
2,5-Dimethyl-[16]	3-, 6-, and 4- (trace)
2-Methyl-5-isopropyl-4-chloro-[17]	?
2-Methyl-4-*tert*-butyl-[18]	3,5-di-
2,4,6-Trimethyl-[19]	3-

The positions taken by the nitro group when various homologs of benzene and their derivatives are nitrated are shown in Table VI.

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[1] (*a*) Schwanert, *Ann.*, **186**, 349 (1877). (*b*) Hirwe and Jambhekar, *J. Indian Chem. Soc.*, **11**, 239 (1934).

[2] Bek, *Z. Chem.*, 210 (1869).

[3] Fichter and Bernoulli, *Ber.*, **42**, 4309 (1909); Beilstein and Kuhlberg, *Ann.*, **156**, 19 (1870); Marckwald, *Ann.*, **274**, 349 (1893); Reverdin and Crépieux, *Bull. soc. chim.*, [3] **25**, 1043 (1901); *Ber.*, **34**, 2995 (1901).

[4] Wynne and Greaves, *Chem. News*, **72**, 58 (1895).

[5] Davies, *J. Chem. Soc.*, **121**, 787 (1922).

[6] Schraube and Romig, *Ber.*, **26**, 579 (1893).

[7] Schäfer, *Ann.*, **174**, 365 (1874).

[8] Hübner and Hasselbarth, *Ann.*, **169**, 22 (1873).

[9] Weckwarth, *Ann.*, **172**, 196 (1874).

[10] Pagel, *Ann.*, **176**, 294 (1875); Hübner and Müller, *Ann.*, **169**, 42 (1873).

[11] Hayduck, *Ann.*, **174**, 347 (1874).

[12] Simonsen, *J. Chem. Soc.*, **103**, 1149 (1913).

[13] Harmsen, *Ber.*, **13**, 1559 (1880).

[14] Karslake and Morgan, *J. Am. Chem. Soc.*, **30**, 828 (1908).

[15] (*a*) Limpricht and Gronow, *Ber.*, **18**, 2192 (1885). (*b*) Claus and Schmidt, *Ber.*, **19**, 1418 (1886)

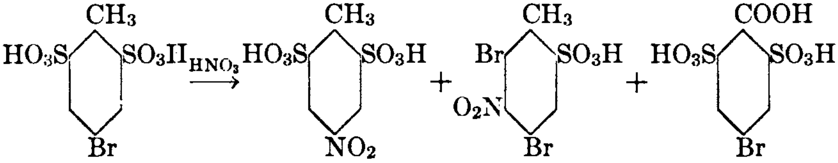
[16] Karslake and Huston, *J. Am. Chem. Soc.*, **36**, 1245 (1914).

[17] Carrara, *Gazz. chim. ital.*, **19**, 170 (1889).

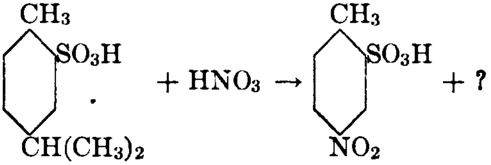
[18] Nölting, *Ber.*, **25**, 787 (1892).

[19] Rose, *Ann.*, **164**, 56 (1872).

In addition, several nitrations in which the sulfo group is replaced are on record. 2,4-Dimethylbenzenesulfonic acid gives as a by-product[184] trinitro-*m*-xylene. A similar change occurs with 2-methyl-4-*tert*-butylbenzenesulfonic acid.[185] In the reaction of boiling nitric acid upon 2-methyl-5-bromobenzene-1,3-disulfonic acid[186] at least three products are formed.



A most remarkable replacement of the isopropyl group occurs in the nitration of 2-methyl-5-isopropylbenzenesulfonic acid.[187]



Nitration of 3-sulfobenzoic acid[188] occurs in position 5.

The nitration of *p*-sulfophenylacetic acid occurs normally, the nitro group entering the *ortho* position.[189] *p*-Sulfobenzyl cyanide when treated with nitrogen oxides in aqueous solution gives the *p*-nitro compound.[178]

The action of nitric acid upon biphenyl-4-sulfonyl chloride yields mostly the 4′-nitro derivative.[190] The 4,4′-disulfonyl chloride also has been nitrated, the nitro groups probably entering the 2,2′-positions. In the case of the 2,2′-disulfonyl chloride[191] one would predict that the 4,4′-dinitrobiphenyl-2,2′-disulfonyl chloride would result. Apparently the structure was not determined.

2′-(4-Sulfobenzoyl)-benzoic acid nitrates in the 4′-position.[192]

Naphthalene-1-sulfonic acid[193] (or the sulfonyl chloride) and the 2-isomer[194] when nitrated yield the 4-, 5-, and 8-nitrosulfonic acids. The 4-nitro compound is always formed in small amount. Further nitration of 5-nitronaphthalene-1-sulfonic acid yields the 4,5-dinitro compound.[195] 5-Nitronaphthalene-2-sulfonic acid[196] or the sulfonyl chloride[197] also substitutes in the 4-position. The 8-nitrosulfonic acid likewise gives the 4,8-dinitro derivative.[198a] The nitration reactions of the naphthalenedisulfonic acids are summarized in Table VII. Lantz [198b] has reported in detail on the nitration of many naphthalenesulfonic acids.

TABLE VII

NAPHTHALENEDISULFONIC ACIDS AND REFERENCES	POSITION(S) OF NITRO GROUP(S)
1,4-[1]	5-
1,5-[2, 3, 5]	3- and 4-; 3,8-di-
1,6-[4, 5]	8- and 3- (small amount); then 3,8-di-
2,6-[6, 7]	3-, then 3,8-di-
2,7-[8, 3]	4-, then 4,5-di-

[1] Bayer and Co., German pat., 70,857, *Frdl.*, **3**, 426.

[2] A.-G. für Anilinfabrik, German pat., 45,776, *Frdl.*, **2**, 253; Cassella and Co., German pat., 65,997 *Frdl.*, **3**, 444; Schultz, *Ber.*, **23**, 77 (1890).

[3] Friedländer and Kielbasinski, *Ber.*, **29**, 1980, 2574 (1896).

[4] Ewer and Pick, German pat., 52,724, *Frdl.*, **2**, 253; Badische Anilin- und Sodafabrik, pat. appl., B9514 and B9548, *Frdl.*, **2**, 269; Friedländer, *Ber.*, **28**, 1535 (1895); Armstrong and Wynne, *Chem. News*, **63**, 124 (1891); Kalle and Co., German pat., 72,665, *Frdl.*, **3**, 481.

[5] Bernthsen, *Ber.*, **22**, 3328 (1889).

[6] Alén, *Ber.*, **17R**, 437 (1884); *Ber.*, **16**, 570 (1883); *Bull. soc. chim.*, [2] **39**, 63 (1883).

[7] Cassella and Co., German pat., 61,174, *Frdl.*, **3**, 483; Bayer and Co., German pat., 126,198, *Frdl.*, **6**, 445.

[8] Armstrong and Wynne, *Ber.*, **29R**, 225 (1896); Cleve, *Ber.*, **25**, 2485 (1892).

The results obtained in the nitration of various chloronaphthalenesulfonyl chlorides are tabulated in Table VIII.

TABLE VIII

NITRATION OF CHLORONAPHTHALENESULFONYL CHLORIDES

Position of Substituent and Reference(s)	Position of Nitro Group
1-Chloro-2-[1]	5- and 7-
1-Chloro-3-[2]	5-
1-Chloro-4-[1]	5- and 8-
1-Chloro-5-[2, 3]	2- and 4- (?)
1-Chloro-6-[1]	4-
1-Chloro-7-[1]	4- and 8-
2-Chloro-5-[1]	1-
2-Chloro-6-[1]	1-
2-Chloro-7-[4]	1-
2-Chloro-8-[1]	1-

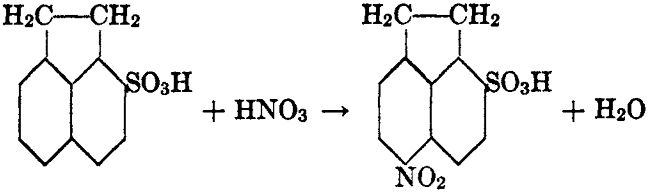
[1] Cleve, *Chem.-Ztg.*, **17**, 398 (1893).

[2] Cleve, *ibid.*, **17**, 758 (1893).

[3] Friedländer, Karamessinis, and Schenk, *Ber.*, **55B**, 49 (1922); (sulfonic acid nitrated).

[4] Cleve, *Ber.*, **25**, 2485 (1892).

The nitration of acenaphthenesulfonic acid [199] occurs as shown.

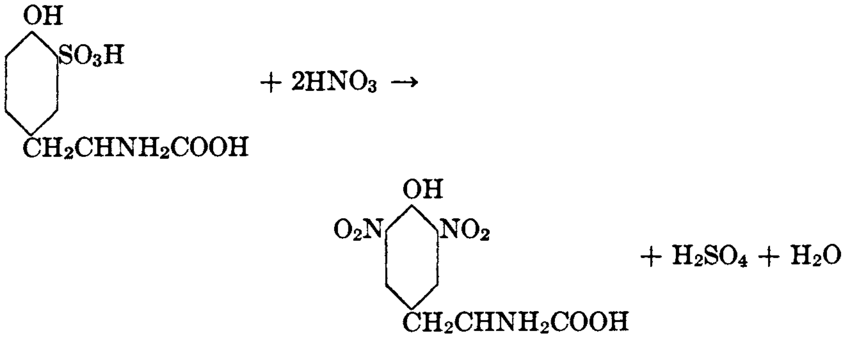


The nitration of phenolsulfonic acids may or may not result in displacement of the sulfo group depending upon the structure of the substance nitrated and the reaction conditions. In general a position *ortho* or *para* to hydroxyl is always nitrated before the sulfo group is removed. This latter is unaffected if it is *meta* to the hydroxyl.

Phenol-*p*-sulfonic acid[200] and the methyl ether[201] have been converted into the 2,6-dinitro compounds by the action of nitric acid. Mononitration of the phenolsulfonic acid[202] can be effected by addition of potassium nitrate to the sulfuric acid solution. Anisole-*p*-sulfonyl chloride has been nitrated with nitric acid at −5° to the 2-nitro derivative.[203] Phenol-*o*-sulfonic acid[204] nitrates *para* to hydroxyl and the 2,4-disulfonic acid may be converted into the 2,6-dinitro compound.[205] Phenol-*m*-sulfonic acid has been trinitrated.[206] Nitration of 2-chlorophenol-4-sulfonic acid[207] yields first the 6-nitro compound and then 4,6-dinitro-2-chlorophenol. 4-Chlorophenol-2-sulfonic acid behaves in an exactly analogous manner.[208] 2,6-Dichlorophenol-4-sulfonic acid has been reported[209] to nitrate to 2-nitro-6-chlorophenol-4-sulfonic acid with loss of a chlorine atom. Nitration of 2-bromo-6-nitrophenol-4-sulfonic acid[210] yields 4,6-dinitro-2-bromophenol. 2-Bromophenol-4,6-disulfonic acid[211] gives this and some 4,6-dibromo-2-nitrophenol by a migration of a bromine atom. This last compound also arises from nitration of 2,4-dibromophenol-6-sulfonic acid. 2,6-Diiodophenol-4-sulfonic acid[212a] with nitric acid gives picric acid. The behavior of 2-hydroxy-3-iodo-5-sulfobenzoic acid is particularly interesting. By the action of nitric acid the iodo, sulfo, and carboxy groups are replaced successively, showing their order of replacement clearly.[212b] The 2- and 3-methylphenol-4-sulfonic acids[213] nitrate in the 6-position. 1-Methoxy-3-methylbenzene-4,6-disulfonyl chloride has been nitrated to the 2-nitro derivative.[214] Treating *p*-cresol with two moles of nitric acid in sulfuric acid gives the 2-nitro-6-sulfonic acid.[215]

By the action of nitric acid upon 2-methyl-6-iodophenol-4-sulfonic acid both the iodo and sulfo groups are replaced.[216]

Nitration of tyrosine-3-sulfonic acid in sulfuric acid solution gives rise to 3,5-dinitrotyrosine.[217]



Nitration of 2-naphthol-6-sulfonic acid yields a mixture of the 1-nitro derivative (13%) and a dinitro compound (32%) of unknown composition.[218a] By further nitration as high as a 78% yield of a dinitro compound was isolated. 1-Methoxynaphthalene-4-sulfonic acid[218b] with nitric acid gives the 4-nitro-1-methoxy compound with elimination of the sulfo group.

By the action of nitrogen oxides upon aminosulfonic acids the sulfonic acid group is replaced by a nitro group, the amine is diazotized and hydrolyzed to a phenol, and usually further nitration also takes place.[219] Thus even metanilic acid is reported to give 2,5-dinitrophenol. Dimethylaniline-4-sulfonic acid yields what is presumably 2,3,4-trinitrodimethylaniline. Nitrous acid gives *p*-nitrodimethylaniline and a nitrosulfonic acid.[220a]

Diphenylamine-4-sulfonic acid with one mole of nitric acid in acetic acid solution[220b] gives 4′-nitrodiphenylamine-4-sulfonic acid. Further nitration produces finally the 2′,4′,6′-trinitrodiphenylamine-4-sulfonic acid whose structure is evident as it has also been obtained from sulfanilic acid and picryl chloride.[221a] Diphenylamine-4,4′-disulfonic acid nitrates first in the 2- and 2′-positions, further reaction replacing the sulfo groups.

1-Naphthylamine-2,4,8-trisulfonic acid upon nitration undergoes replacement of the 2- and 4-sulfo groups. The same dinitro compound was obtained from the sultam of 1-aminonaphthalene-8-sulfonic acid.[221b] 1-Amino-2-naphthol-4-sulfonic acid[222] and the corresponding diazo compound[223] nitrate in the 6-position.

Treatment of 2-aminopyridine-5-sulfonic acid with fuming nitric acid in sulfuric acid solution[224] results in substitution *ortho* to the amino group.

REFERENCES FOR A. PHYSICAL PROPERTIES OF AROMATIC SULFONIC ACIDS AND THEIR SALTS AND B. HYDROLYSIS, REDUCTION, AND OXIDATION REACTIONS OF SULFONIC ACIDS

1*a*. Ostwald, *Z. physik. Chem.*, **1**, 76 (1887). *b*. Jeffery and Vogel, *J. Chem. Soc.*, 400 (1932). *c*. Hantzsch and Langbein, *Z. anorg. allgem. Chem.*, **204**, 193 (1932). *d*. Hantzsch and Weissberger, *Z. physik. Chem.*, **125**, 251 (1927). *e*. Darmois and Heng, *Compt. rend.*, **199**, 1123 (1934). *f*. Müller, *Z. anorg. allgem. Chem.*, **217**, 113 (1934). *g*. Russell and Cameron, *J. Am. Chem. Soc.*, **60**, 1345 (1938).

2. Elgersma, *Rec. trav. chim.*, **48**, 770 (1929).
3. Ostwald, *Z. physik. Chem.*, **2**, 850 (1888).
4. Hammett and Deyrup, *J. Am. Chem. Soc.*, **54**, 4239 (1932).
5. Murray-Rust and Hartley, *Proc. Roy. Soc.*, **126A**, 84 (1929).
6. Berthelot, *Compt. rend.*, **82**, 185 (1871); *Ann. chim. phys.*, [5] **9**, 297, 304 (1870).
7. Seyewetz and Poizat, *Bull. soc. chim.*, **9**, 247 (1911).
8. Fischer, *Ber.*, **39**, 4144 (1906).
9. Cooke, *J. Soc. Chem. Ind.*, **40**, 56T, 239T (1921).
10. Rhodes and Lewis, *Ind. Eng. chem.*, **20**, 1366 (1928).
11. Maxin, German pat., 293,982, *C.A.*, **11**, 2581 (1917).
12. Hillyer, U. S. pat., 1,546,239, *C.A.*, **20**, 423 (1926).
13. Cobellis, British pat., 134,715, *C.A.*, **14**, 946 (1920).
14. Dennis, French pat., 483,716, *C.A.*, **12**, 909 (1918).
15. Čupr and Širůček, *J. prakt. Chem.*, [2] **136**, 159 (1933); **139**, 245 (1934); see also Ephraim and Pfister, *Helv. Chim. Acta*, **8**, 229 (1925).
16. Dominikiewicz, *C.A.*, **28**, 5421 (1934).
17. Ephraim, *Ber.*, **54B**, 965 (1921).
18. Zimmermann, *Z. physiol. Chem.*, **188**, 180 (1930); **189**, 155 (1930).
19. Doherty, Stein, and Bergmann, *J. Biol. Chem.*, **135**, 487 (1940).
20. Schaefer, *J. Soc. Chem. Ind.*, **29**, 928T (1910).
21. Limburg, German pat., 551,425, *C.A.*, **26**, 4347 (1932).
22. Chambers and Scherer, *Ind. Eng. Chem.*, **16**, 1272 (1924); Donleavy, *J. Am. Chem. Soc.*, **58**, 1004 (1936); Garner, *J. Soc. Dyers Colourists*, **51**, 302 (1936); Chambers and Watt, *J. Org. Chem.*, **6**, 376 (1941).
23. Archer, unpublished results, this laboratory.
24. Perkin and Sewell, *J. Soc. Chem. Ind.*, **42**, 27T (1923).
25. Ambler, *J. Ind. Eng. Chem.*, **12**, 1081 (1920).
26. Forster and Keyworth, *J. Soc. Chem. Ind.*, **43**, 165T (1924).
27. Ambler and Wherry, *J. Ind. Eng. Chem.*, **12**, 1085 (1920).
28. Keyworth, *J. Soc. Chem. Ind.*, **43**, 341T (1924).
29. Keyworth, *ibid.*, **46**, 20T, 397T (1927).
30. Noller and Liang, *J. Am. Chem. Soc.*, **54**, 670 (1932).
31. Forster and Keyworth, *J. Soc. Chem. Ind.*, **43**, 299T (1924).
32. Ambler, *J. Ind. Eng. Chem.*, **12**, 1081 (1920); Wales, *ibid.*, **14**, 317 (1922); Forster and Keyworth, *J. Soc. Chem. Ind.*, **43**, 165T (1924); Forster and Hishiyama, *ibid.*, **51**, 297T (1932).
33. Forster and Keyworth, *ibid.*, **46**, 25T (1927).

34. Forster and Watson, *ibid.*, **46**, 224T (1927).

35. Forster, Hanson, and Watson, *ibid.*, **47**, 155T (1928).

36. Perkin and Sewell, *ibid.*, **42**, 27T (1923).

37*a*. Freund, *Ann.*, **120**, 80 (1861). *b*. Beilstein and Wahlforss, *Ann.*, **133**, 30 (1864). *c*. Armstrong and Miller, *J. Chem. Soc.*, **45**, 148 (1884); *Chem. News,* **49**, 121 (1884). *d*. Kelbe, *Ber.*, **19**, 92 (1886). *e*. Friedel and Crafts, *Compt. rend.*, **109**, 95 (1889). *f*. Fournier, *Bull. soc. chim.*, [3] **7**, 652 (1892). *g*. Limpricht, *Ber.*, **10**, 1539 (1887). *h*. Langfurth, *Ann.*, **191**, 188 (1878). *i*. Spica, *Gazz. chim. ital.*, **12**, 543 (1882). *j*. Kelbe and Koschnitzky, *Ber.*, **19**, 1730 (1886). *k*. Ges. für Chem. Ind., German pat., 133,000, *Chem. Zentr.*, II, 313 (1902). *l*. Claus and Immel, *Ann.*, **265**, 77 (1891). *m*. Schultz, *Ber.*, **42**, 3603 (1909); Jacobsen and Meyer, *Ber.*, **16**, 190 (1883); Ipatieff and Petrov, *Ber.*, **59B**, 1737 (1926).

38. Jacobsen, *Ber.*, **19**, 1210 (1886); **20**, 900 (1887).

39*a*. Crafts, *J. Am. Chem. Soc.*, **23**, 248 (1901); *Ber.*, **34**, 1360 (1901); *Bull. soc. chim.*, [4] **1**, 917 (1907). *b*. Veselý and Stojanova, *Collection Czechoslov. Chem. Commun.*, **9**, 465 (1937); *C.A.*, **32**, 1549 (1938).

40. Hoogewerff and Van Dorp, *Rec. trav. chim.*, **21**, 359 (1902).

41. Klages, *J. prakt. Chem.*, [2] **65**, 396 (1902).

42. Reinke, *Ann.*, **186**, 272 (1877); Bassmann, *Ann.*, **191**, 208 (1878).

43. Ullmann and Kuhn, *Ann.*, **366**, 102 (1909).

44. Orlov, *Ukrainskii Khem. Zhurnal*, **2**, 365 (1926); *C.A.*, **22**, 1762 (1928); Kizhner, *J. Gen. Chem. (U.S.S.R.)*, **3**, 578 (1933); *C.A.*, **28**, 2693 (1934); Crafts, *Compt. rend.*, **114**, 1110 (1892).

45. Schroeter and Gotzky, *Ber.*, **60B**, 2035 (1927).

46. Schreiber and Shriner, *J. Am. Chem. Soc.*, **56**, 1618 (1934).

47. Wynne, *J. Chem. Soc.*, **61**, 1038 (1892); Klages and Stamm, *Ber.*, **37**, 1719 (1904).

48*a*. Merz, *Z. Chem.*, 399 (1868). *b*. Merz and Weith, *Ber.*, **3**, 196 (1870). *c*. Friedländer and Lucht, *Ber.*, **26**, 3030 (1893). *d*. Shreve, *Color Trade J.*, **14**, 42 (1924).

49. Ambler and Scanlan, *Ind. Eng. Chem.*, **19**, 417 (1927).

50. Lynch and Scanlan, *ibid.*, **19**, 1010 (1927).

51. Weissgerber and Kruber, *Ber.*, **52**, 348 (1919). Ges. für Teerverwertung, German pat., 301,079, *Chem. Zentr.*, II, 713 (1917).

52. Armstrong and Wynne, *Chem. News,* **76**, 69 (1897); **59**, 189 (1889); **61**, 275 (1890); Cleve, *Chem.-Ztg.*, **17**, 389 (1893); *Ber.*, **25**, 2487 (1892); Arnell, dissertation, Upsala, 1889.

53. Obermiller, *J. prakt. Chem.*, [2] **84**, 459 (1911).

54. Benedikt and Bamberger, *Monatsh.*, **12**, 4 (1891).

55. Hazard-Flamand, German pat., 141,751, *Chem. Zentr.*, I, 1324 (1903); Huston and Ballard, *Org. Syntheses,* **14**, 14 (1934).

56. Bruckner, *Z. anal. Chem.*, **75**, 289 (1928).

57. Merck, German pat., 80,817, *Frdl.*, **4**, 116; Tobias, German pat., 81,209, *Frdl.*, **4**, 117.

58. A.-G. für Anilinfabrik, German pat., 207,374, *Chem. Zentr.*, I, 1128 (1909).

59. Graebe, *Ann.*, **146**, 40 (1868).

60. Dziewoński and Loewenhof, *C.A.*, **22**, 2560 (1928); Nietzki, *Ber.*, **15**, 305 (1882); Tobias, German pat., 74,668, *Frdl.*, **3**, 440.

61. Bender, *Ber.*, **22**, 999 (1889); Conrad and Fischer, *Ann.*, **273**, 111 (1892).

62. Friedländer and Taussig, *Ber.*, **30**, 1460 (1897).

63. König, *Ber.*, **23**, 806 (1890).

64*a*. Bayer and Co., German pat., 78,569, *Frdl.*, **4**, 538. *b*. Dressel and Kothe, *Ber.*, **27**, 1209 (1894).

65*a*. Bayer and Co., German pat., 67,829, *Frdl.*, **3**, 447. *b*. German pat., 87,429, *Frdl.*, **4**, 584. *c*. Bayer and Co., German pat., 90,878, *Frdl.*, **4**, 1334. *d*. German pat., 89,539, *Frdl.*, **4**, 613. *e*. Friedländer and Zinberg, *Ber.*, **29**, 39 (1896). *f*. Leman, *Ann. chim.*, 9, 372 (1938).

66. Richter, *Ann.*, **230**, 315 (1885).

67*a*. Kalle and Co., German pat., 62,634, *Frdl.*, **3**, 431; *Ber.*, **25R**, 700 (1892). *b*. German pat., 78,603, *Frdl.*, **4**, 535. *c*. Bucherer and Wahl, *J. prakt. Chem.*, [2] **103**, 135 (1921).

68. Kalle and Co., German pat., 80,878, *Frdl.*, **4**, 578; German pat., 83,146, *Frdl.*, **4**, 529; Dressel and Kothe, *Ber.*, **27**, 1199 (1894).

69. Erdmann, *Ann.*, **247**, 328 (1888); **275**, 198 (1893).

70. Höchster Farbw., German pat., 71,494, *Frdl.*, **3**, 423; Kalle and Co., German pat., 64,979, *Frdl.*, **3**, 425.

71. Kalle and Co., German pat., 82,563, *Frdl.*, **4**, 519.

72. Cassella and Co., German pat., 188,505, *Frdl.*, **8**, 1360; *Chem. Zentr.*, II, 1467 (1907).

73. Höchster Farbw., German pat., 73,076, *Frdl.*, **3**, 496.

74*a*. Bayer and Co., German pat., 89,242, *Frdl.*, **4**, 592; German pat., 84,990, *Frdl.*, 4, 229; German pat., 80.668, *Frdl.*, **4**, 562; Friedländer and Rudt, *Ber.*, **29**, 1609 (1896). *b*. Ullmann and Dahmen, *Ber.*, **41**, 3755 (1908).

75*a*. Lauer, *J. prakt. Chem.*, [2] **135**, 182 (1932). *b*. Bayer and Co., German pat., 160,104, *Frdl.*, **8**, 236; *Chem. Zentr.*, I, 1447 (1905). *c*. Federov and Sheludyakova, *J. Gen. Chem. (U.S.S.R.)*, **8**, 1699 (1938).

76. Berkenheim and Znamenskaya, *ibid.*, **4**, 31 (1934); *C.A.*, **28**, 5434 (1934).

77. Höchster Farbw., German pat., 71,964, *Frdl.*, **3**, 244; Offermann, *Ann.*, **280**, 12 (1894); Graebe, *Ber.*, **12**, 572 (1879); *Ann.*, **349**, 206 (1906); Bayer and Co., German pat., 178.631, *Frdl.*, **8**, 255; Marschalk, *Bull. soc. chim.*, **41**, 943 (1927).

78. Bayer and Co., German pat., 172,688, *Frdl.*, **8**, 260; *Chem. Zentr.*, II, 646 (1906); German pat., 56,951, *Frdl.*, **3**, 269; Wedekind and Co., German pat., 210,863, *Frdl.*, **9**, 688; *Chem. Zentr.*, II, 243 (1909).

79. Höchster Farbw., German pat., 84,774, *Frdl.*, **4**, 279.

80. Badische Anilin- und Sodafabrik, German pat., 153,129 and 154,337, *Frdl.*, **7**, 184, 218; *Chem. Zentr.*, II, 751, 1080 (1904).

81. Bayer and Co., German pat., 172,688, *Frdl.*, **8**, 261; *Chem. Zentr.*, II, 646 (1906).

82. Marschalk, *Bull. soc. chim.*, **41**, 943 (1927).

83. Fieser, *J. Am. Chem. Soc.*, **50**, 465 (1928).

84. Muth and Schmelzer, U. S. pat., 1,931,826, *C.A.*, **28**, 491 (1934); I. G. Farbenind. A.-G., British pat., 417,794, *C.A.*, **29**, 1438 (1935).

85. Matsui and Sakurada, *Mem. Coll. Sci. Kyoto Imp. Univ.*, **15A**, 181 (1932); *C.A.*, **26**, 5264 (1932).

86. Claus, *Ber.*, 10, 1304 (1877).

87. Bayer and Co., German pat., 255,724, *Chem. Zentr.*, I, 478 (1913); Kalle and Co., German pat., 233,934, *Frdl.*, **10**, 184; Friedländer and Kielbasinski, *Ber.*, **29**, 1979 (1896); Friedländer and Taussig, *Ber.*, **30**, 1463 (1897);

Gattermann and Schulze, *Ber.*, **30**, 51 (1897); Jacchia, *Ann.*, **323**, 127 (1902); Gattermann and Liebermann, *Ann.*, **393**, 211 (1912); Weil and Heerdt, *Ber.*, **55B**, 227 (1922).

88. Friedländer, Karamissinis, and Schlenk, *Ber.*, **55B**, 45 (1922).
89. Dziewoński and Stolyhwo, *Ber.*, **57B**, 1531 (1924).
90. Liebermann and Bischoff, *Ber.*, **13**, 47 (1880); Liebermann, *Ann.*, **212**, 57 (1882).
91. I. G. Farbenind. A.-G., German pat., 557,246, *C.A.*, **27**, 311 (1933).
92. Liebermann and Zsuffa, *Ber.*, **43**, 1007 (1910).
93. Bayer and Co., German pat., 103,898, *Frdl.*, **5**, 267.
94. Schmidt, U. S. pat., 1,650,158, *C.A.*, **22**, 433 (1928); Grossmann, U. S. pat., 1,903,862, *C.A.*, **27**, 3224 (1933); Swiss pat., 152,613, *C.A.*, **27**, 1005 (1933); Schmidt, German pat., 568,760, *C.A.*, **27**, 2695 (1933); see also Berkenheim and Znamenskaya, *J. Gen. Chem.* (*U.S.S.R.*), **4**, 31 (1934); *C.A.*, **28**, 5434 (1934).
95. Datta and Bhoumik, *J. Am. Chem. Soc.*, **43**, 314 (1921).
96. Kelbe, *Ber.*, **16**, 618 (1883).
97. Höchster Farbw., German pat., 286,712, *Chem. Zentr.*, II, 731 (1915); *Frdl.*, **12**, 105; German pat., 287,932, *Chem. Zentr.*, II, 1061 (1915).
98. Soc. anon, pour l'ind. à Bâle, French pat., 483,690, *C.A.*, **17**, 771 (1923); Ges. für Chem. Ind. Basel, German pat., 312,959, *Chem. Zentr.*, IV, 373 (1919); *Frdl.*, **13**, 220; Rohner and Co., German pat., 293,319, *Chem. Zentr.*, II, 359 (1916); *Frdl.*, **13**, 220.
99. Ris and Simon, *Ber.*, **30**, 2619 (1897); Green and Wahl, *Ber.*, **30**, 3100 (1897); Green, Marsden, and Scholefield, *J. Chem. Soc.*, **85**, 1433 (1904).
100. Rudolph, German pat., 103,983, *Chem. Zentr.*, II, 949 (1899).

101*a*. Rudolph, German pat., 101,349, *ibid.*, I, 960 (1899). *b*. Kozlov and Talybov, *J. Gen. Chem.* (*U.S.S.R.*), 9, 1827 (1939); *C.A.*, **34**, 4067 (1940).

102*a*. Widman, *Ber.*, **12**, 960, 2229 (1879). *b*. Meyer, *Monatsh.*, **36**, 719 (1915). *c*. Varma, Parekh, and Subramanium, *J. Indian Chem. Soc.*, **16**, 460 (1939).

103. Armstrong and Williamson, *Chem. News*, **54**, 256 (1886).
104. Kalle and Co., A.-G., German pat., 343,147, *C.A.*, **17**, 1244 (1923).
105. Marvin, U. S. pat., 1,442,491, *C.A.*, **17**, 1030 (1923).
106. Gubelmann, Weiland, and Stallmann, *J. Am. Chem. Soc.*, **53**, 1033 (1931); Schilling, *Ber.*, **46**, 1066 (1913); Farb. vorm. Bayer and Co., German pat., 205,195, *Frdl.*, 9, 673; Badische Anilin- und Sodafabrik, German pat., 214,714, *Frdl.*, 9, 678; Lauer, *J. prakt. Chem.*, [2] **135**, 182 (1932); see also Ullmann and Kertesz, *Ber.*, **52B**, 545 (1919).
107. Fierz-David, Krebser, and Anderau, *Helv. Chim. Acta*, **10**, 197 (1927); Goldberg, *J. Chem. Soc.*, 73 (1932).
108. Ruggli and Merz, *Helv. Chim. Acta*, **12**, 71 (1929).
109. Datta and Mitter, *J. Am. Chem. Soc.*, **41**, 2028 (1919).
110. Hazard-Flamand, German pat., 141,751, *Chem. Zentr.*, I, 1324 (1903); Tanaka and Kutani, *J. Pharm. Soc. Japan*, No. 541, 196 (1927); *C.A.*, **21**, 2255 (1927).
111. Kolbe and Gauhe, *Ann.*, **147**, 76 (1868); Armstrong, *J. Chem. Soc.*, **24**, 1118 (1872).

112*a*. Huston and Neely, *J. Am. Chem. Soc.*, **57**, 2176 (1935). *b*. Hodgson and Kershaw, *J. Chem. Soc.*, 1419 (1930).

113. Huston and Chen, *J. Am. Chem. Soc.*, **55**, 4214 (1933).
114. Armstrong and Brown, *J. Chem. Soc.*, **25**, 858 (1873).
115. Gnehm and Gnecht, *J. prakt. Chem.*, [2] **73**, 524 (1905).
116. Raschig, German pat., **160,304**, *Chem. Zentr.*, I, 1448 (1905).
117. Raschig, "Schwefel- and Stickstoff-studien," Verlag Chemie G.m.b.H., 1924, p. 250.
118. Heller, *Ber.*, **46**, 2703 (1913).
119. Beckurts, *Ann.*, **181**, 209 (1876).
120. Kränzlein, Roemer, and Kronholz, U. S. pat., 1,914,433, *C.A.*, **27**, 4249 (1933).
121*a*. Swietoslawski, Piltz, and Kraczkiewicz, *Roczniki Chem.*, **11**, 40 (1931); *C.A.*, **25**, 3331 (1931). *b*. Steiger, German pat., 536,995, *C.A.*, **26**, 2747 (1932).
122. Genz, *Ber.*, **2**, 405 (1869).
123*a*. Garrick, *Z. Chem.*, 549 (1869). *b*. Oda and Tamura, *Sci. Papers Inst. Chem. Research (Tokyo)*, **33**, No. 728, 129 (1937); *C.A.*, **32**, 2518 (1938).
124. Nölting and Plawski, *Ber.*, **8**, 819 (1875).
125. Limpricht, *Ann.*, **186**, 135 (1877).
126. Goslich, *Ann.*, **186**, 149 (1877).
127*a*. Kelbe and Stein, *Ber.*, **19**, 2137 (1886). *b*. Stallard, *J. Chem. Soc.*, **89**, 809 (1906).
128. Weinberg, *Ber.*, **11**, 1063 (1878).
129. Pollak and Meissner, *Monatsh.*, **50**, **237** (1928).
130*a*. Kelbe, *Ber.*, **15**, 39 (1882). *b*. Kelbe, *Ann.*, **210**, 49 (1881). *c*. Kelbe and Czarnomski, *Ann.*, **235**, 272 (1886); *Ber.*, **17**, 1747 (1884).
131. Kelbe and Koschnitzky, *Ber.*, **19**, 1730 (1886).
132. Baur, *Ber.*, **27**, 1619 (1894).
133. Kelbe and Pathe, *Ber.*, **19**, 1546 (1886).
134. Rose, *Ann.*, **164**, 56 (1872).
135. Backer, *Rec. trav. chim.*, **54**, 544 (1935).
136. Töhl and Geyger, *Ber.*, **25**, 1538 (1892).
137. Klages and Stamm, *Ber.*, **37**, 1719 (1904).
138. Schroeter and Gotzky, *Ber.*, **60B**, 2035 (1925).
139. Darmstaedter and Wichelhaus, *Ann.*, **152**, 303 (1869); Zal'kind, Veisbrut, and Alekseeva, *J. Gen. Chem. (U.S.S.R.)*, **3**, 892 (1933); *C.A.*, **28**, 6136 (1934).
140. Jolin, *Bull. soc. chim.*, [2] **28**, 517 (1877).
141. Zal'kind and Belikova, *J. Gen. Chem. (U.S.S.R.)*, **4**, 1211 (1934); *C.A.*, **29**, 3331 (1935).
142. Armstrong and Wynne, *Chem. News*, **54**, 256 (1886).
143. Armstrong and Rossiter, *ibid.*, **65**, 58 (1892).
144. Armstrong and Williamson, *ibid.*, **54**, 256 (1886).
145*a*. Senhofer, *Ann.*, **156**, 114 (1870). *b*. Allain-Le Canu, *Compt. rend.*, **109**, 306 (1889).
146*a*. Armstrong and Brown, *J. Chem. Soc.*, **25**, 858 (1873). *b*. Allain-Le Canu, *Compt. rend.*, **103**, 386 (1886); *Bull. soc. chim.*, [2] **47**, 880 (1887). *c*. Senhofer, *Ann.*, **156**, 103 (1870).
147*a*. Armstrong and Brown, *Ber.*, **7**, 924 (1874). *b*. Post and Brackebusch, *Ann.*, **205**, 91 (1880). *c*. Elgersma, *Rec. trav. chim.*, **48**, **752** (1929).
148. Armstrong, *J. Chem. Soc.*, **25**, 865 (1873); Schmidt, *Ber.*, **11**, **852** (1878).

149. Sakellarious, *Ber.*, **55B**, 2846 (1922).
150. Hübener, *Chem.-Ztg.*, **32**, 485 (1908); Obermiller, *Ber.*, **42**, 4361 (1909).
151. Lauer and Langkammerer, *J. Am. Chem. Soc.*, **56**, 1628 (1934).
152. Claus and Jackson, *J. prakt. Chem.*, [2] **38**, 334 (1888); Claus and Dreher, *ibid.*, [2] **39**, 368 (1889).
153. Lewis, *J. Chem. Soc.*, **83**, 330 (1903).
154. Claus and Krause, *J. prakt. Chem.*, [2] **43**, 345 (1891).
155. Kehrmann, *Ber.*, **22**, 3268 (1889).
156. Meldrum and Shah, *J. Chem. Soc.*, **123**, 1986 (1923).
157. Shah, Bhatt, and Kanga, *J. Univ. Bombay*, **3**, 153 (1934).
158. Lippmann, *Jahresbericht*, 739 (1870).
159. Suter, *J. Am. Chem. Soc.*, **53**, 1112 (1931).
160. Krauss and Crede, *ibid.*, **39**, 1431 (1917).
161. Heller, Eisenschmidt, Reichardt, and Wild, *Z. angew. Chem.*, **41**, 171 (1928).
162. Limpricht, *Ann.*, **181**, 193 (1876); *Ber.*, 9, 474 (1876).
163. Berndsen and Limpricht, *Ann.*, **177**, 100 (1875).
164. Francis and Hill, *J. Am. Chem. Soc.*, 46, 2500 (1924).
165. Sudborough and Lakhumalani, *J. Chem. Soc.*, **111**, 41 (1917).
166. Fuchs, *Monatsh.*, **36**, 113 (1915).
167. Berndsen, *Ann.*, **177**, 82 (1875); Beckurts, *Ann.*, **181**, 209 (1876); Limpricht and Langfurth, *Ann.*, **191**, 176 (1878).
168. Heinzelmann, *Ann.*, **188**, 183 (1877).
169. Amiantov and Titkov, *Anilinokrasochnaya Prom.*, **2**, No. 8-9, 24 (1932); *C.A.*, 27, 5315 (1933).
170. Francis, *J. Am. Chem. Soc.*, **48**, 1632 (1926).
171. Dziewoński and Russocki, *Bull. intern. acad. polonaise*, 506 (1929A); *C.A.*, **25**, 1503 (1931).
172. Heller, Arnold, and Schmidt, *Z. angew. Chem.*, **43**, 1132 (1930).
173. Forsyth, Moore, and Pyman, *J. Chem. Soc.*, **125**, 919 (1924).
174. Kehrmann, *J. prakt. Chem.*, [2] **37**, 11, 334 (1888); Trommsdorff, German pat., 45,226, *Frdl.*, **2**, 510.
175. Weiler-ter-Meer, German pat., 124,231, *Chem. Zentr.*, II, 961 (1901).
176. Kehrmann, *J. prakt. Chem.*, [2] **39**, 392 (1889); **37**, 338 (1888).
177. Trommsdorff, German pat., 45,226, *Frdl.*, **2**, 511.
178. Datta and Varma, *J. Am. Chem. Soc.*, **41**, 2047 (1919).
179. Limpricht, *Ann.*, **177**, 62 (1875).
180. Obermiller, *J. prakt. Chem.*, [2] 89, 70 (1914); *Z. ang. Chem.*, 27, 38 (1914).
181. Fierz, Schlittler, and Waldmann, *Helv. Chim. Acta*, **12**, 663 (1929); see also Ekbom, *Ber.*, **35**, 651 (1902).
182. Limpricht, *Ber.*, 8, 289 (1875); 9, 554 (1876); Sachse, *Ann.*, **188**, 144 (1877).
183. Heinzelmann, *Ann.*, 188, 161 (1877); Bennett and Willis, *J. Chem. Soc.*, 256 (1929).
184. Limpricht and Gronow, *Ber.*, **18**, 2192 (1885); Karslake and Morgan, *J. Am. Chem. Soc.*, **30**, 828 (1908).
185. Nölting, *Ber.*, **25**, 787 (1892).
186. Kornatzki, *Ann.*, **221**, 195 (1883).
187. Osakeyhitiö, Swedish pat., 42,517, *C.A.*, **11**, 2679 (1917); Danish pat., 23,344, *C.A.*, **13**, 230 (1919); Hintrikka, *Ann., Acad. Sci. Fennicae*, [A] **10**, 1 (1917); *C.A.*, **15**, 2838 (1921).

188. Holleman and van Dorssen, *Rec. trav. chim.*, **29**, 368 (1910); Shah and Bhatt, *J. Chem. Soc.*, 1373 (1933).

189. Martinet and Dornier, *Compt. rend.*, **172**, 1415 (1921).

190. Gabriel and Dambergis, *Ber.*, **13**, 1408 (1880).

191. Limpricht, *Ann.*, **261**, 327 (1891).

192. Gubelmann, Weiland, and Stallmann, *J. Am. Chem. Soc.*, **53**, 1033 (1931).

193. Laurent, *Ann.*, **72**, 298 (1849); *Compt. rend.*, **31**, 537 (1850); Cleve, *Ber.*, **10**, 1722 (1877); **23**, 958 (1890); *Bull. soc. chim.*, [2] **24**, 507 (1875); Schoellkopf and Co., German pat., 40,571, *Frdl.*, **1**, 393; Bernthsen, *Ber.*, **23**, 3088 (1890); Erdmann, *Ann.*, **247**, 312 (1888); Erdmann and Süvern, *Ann.*, **275**, 231 (1893); Steiger, *Helv. Chim. Acta*, **17**, 794 (1934).

194. Cleve, *Ber.*, **19**, 2179 (1886); **21**, 3264 (1888); *Bull. soc. chim.*, [2] **26**, 444 (1876); Armstrong and Wynne, *Chem. News*, **59**, 95 (1889); **73**, 55 (1896); Fabrowicz and Lésniański, *Roczniki Chem.*, **11**, 636 (1931); *C.A.*, **26**, 3791 (1932).

195. Cassella and Co., German pat., 70.019, *Frdl.*, **3**, 454.

196. Cassella and Co., German pat., 67,017, *Frdl.*, **3**, 456.

197. Hellstrom, "Öfversigt af K. Vetenskaps Akademiens forhandlingar," Stockholm, 1888, p. 615.

198*a*. Cassella and Co., German pat., 85,058, *Frdl.*, **4**, 580. *b*. Lantz, *Bull. soc. chim.*, **6**, 280 (1939).

199. Dziewoński and Orzelski, *Bull. intern. acad. polonaise*, 347 (1926A); *C.A.*, **22**, 1160 (1928).

200. Beyer and Kegel, German pat., 27,271, *Frdl.*, **1**, 324.

201. Höchster Farbw., German pat., 148,085, *Chem. Zentr.*, I, 135 (1904).

202. Kolbe and Gauhe, *Ann.*, **147**, 71 (1868).

203. Gnehm and Knecht, *J. prakt. Chem.*, [2] **74**, 95 (1906).

204. Post and Stuckenberg, *Ann.*, **205**, 45 (1880).

205. Post, *Ber.*, **7**, 1323 (1874).

206. Schultz and Ichenhaeuser, *J. prakt. Chem.*, [2] **77**, 114 (1908); Berndsen, *Ann.*, **177**, 90 (1875).

207. Armstrong, *Ber.*, **7**, 405 (1874).

208. Badische Anilin- und Sodafabrik, German pat., 132,423, *Frdl.*, **6**, 118.

209. Armstrong, *J. Chem. Soc.*, **24**, 1117 (1871).

210. Armstrong and Brown, *Ber.*, **7**, 924 (1874); Sakellarios, *Ber.*, **55B**, 2816 (1922).

211. Armstrong, *J. Chem. Soc.*, **25**, 867 (1872).

212*a*. Kehrmann, *J. prakt. Chem.*, [2] **37**, 334 (1888). *b*. Ishihara, *J. Pharm. Soc. Japan*, **49**, 759 (1929); *C.A.*, **24**, 601 (1930).

213. Schultz, *Ber.*, **40**, 4319 (1907).

214. Haworth and Lapworth, *J. Chem. Soc.*, **123**, 2982 (1923).

215. Borsche and Fiedler, *Ber.*, **46**, 2117 (1913).

216. Kehrmann, *J. prakt. Chem.*, [2] **37**, 334 (1888).

217. Conklin and Johnson, *J. Am. Chem. Soc.*, **54**, 2914 (1932).

218*a*. Vorozhtzov and Kasatkin, *C.A.*, **23**, 3697 (1929). *b*. Vorozhtzov, *Chem. Zentr.*, I, 651 (1911); II, 612.

219. Datta and Varma, *Quart. J. Indian Chem. Soc.*, **4**, 321 (1927).

220*a*. Davidson and Reade, *J. Chem. Soc.*, 1701 (1939). *b*. Dziewoński and Russocki, *Bull. intern. acad. polonaise*, 506 (1929A); *C.A.*, **25**, 1503 (1931).

221*a*. Turpin, *J. Chem. Soc.*, **59**, 717 (1891). *b*. Dannerth, *J. Am. Chem. Soc.*, **29**, 1327 (1907).
222. Battegay, Silbermann, and Kienzle, *Bull. soc. chim.*, [4] **49**, 716 (1931).
223. Ruggli, Knapp, Merz, and Zimmermann, *Helv. Chim. Acta*, **13**, 1034 (1930).
224. Räth, *Ann.*, **487**, 105 (1931).

C. REACTION OF METAL SULFONATES WITH BASES AND SALTS

THE REACTIONS OF METAL SULFONATES WITH ALKALI

The interaction of aromatic sulfonic acid salts and alkali at a high temperature has received much study, chiefly because of the industrial importance and scientific interest in the resulting phenols. While phenol itself is now prepared to a large extent by other methods the majority of the common phenolic compounds including a variety of naphthol derivatives useful as dye intermediates are still obtained from sulfonic acids. Some limitations of this method for preparing phenolic substances may, however, be mentioned. The presence of a hydroxyl or amino group *ortho* or *para* to the sulfonic acid substituent has a profound effect in that the sulfo group is much less reactive, and when replacement does occur it is accompanied by rearrangement or complete decomposition of the molecule. The nitro group likewise interferes with phenol formation since in a fusion mixture it acts as an oxidizing agent with consequent complete breakdown of the nitrosulfonic acid to ammonia, oxalic acid, and other products.[1] However, in 2,4-dinitrobenzenesulfonic acid the activating influence of the nitro groups is such that aqueous alkali readily gives 2,4-dinitrophenol.[2a] If a methyl group is present in the *para* position as in 4-nitrotoluene-2-sulfonic acid a mixture of dyestuffs related to stilbene results.[2b] On the other hand, 2-nitrotoluene-4-sulfonic acid goes over to 2-amino-4-sulfobenzoic acid.[2c]

Benzenesulfonic Acid. It was reported simultaneously by Wurtz, Kekulé, and Dusart[3] that heating potassium benzenesulfonate with potassium hydroxide at a high temperature converts it into phenol and potassium sulfite. Sodium hydroxide brings about the same change and because it is cheaper is always employed when the reaction is run on a large scale.[4] Several careful studies of the effect of reaction conditions upon the yield of phenol have been made. Excellent results are obtained with a 15% excess of sodium hydroxide, a fusion temperature of 350°, and a heating time of 15 minutes after all the sodium sulfonate is added, the yield of phenol attaining 96% of the theoretical amount. At a temperature as low as 300° the yield is nearly as good provided the fusion time is 30 minutes and a 50% excess of alkali is used.[5] In essentially a confirmation of these results 94–96% yields of phenol have been reported[6] for a 15- to 30-minute fusion time at 320–330°, longer heating increasing the by-products at the expense of the phenol. The presence of up to 10% sodium sulfate in the fusion mixture did not change the yield, whereas 8% of sodium carbonate increased it slightly and iron or sodium chloride had an adverse effect. Rather surprisingly sodium chlorate has little effect on the phenol, only the sodium sulfite being oxidized. When the reaction is run on a small scale[7] (1 g. of sulfonate to 2.5 g. of alkali) fusions at 325° in the presence of oxygen give side reactions involving the loss of free hydrogen which reduces the yield of phenol to 90% whereas in an oxygen-free atmosphere it is practically quantitative.

A variety of by-products has been separated from phenol fusion mixtures. If sodium benzenesulfonate is heated with dilute 10% sodium hydroxide at high temperature and pressure considerable benzene[8] is formed along with the phenol although this seems not to have been reported from fusion reactions. In the fusion mixture dehydrogenation apparently occurs in at least two different ways;[9a] there is the hydroxylation of the phenol by sodium hydroxide and also the loss of hydrogen between two benzene nuclei with the resultant formation of derivatives of biphenyl.

$$C_6H_5ONa + NaOH \rightarrow C_6H_4(ONa)_2 + H_2$$
$$2C_6H_5ONa \rightarrow (C_6H_4ONa)_2 + H_2$$

Compounds which have been identified from these and other reactions include resorcinol, *p*-hydroxybiphenyl, 2,2′-dihydroxybiphenyl,[6] phenyl ether, and perhaps a trace of biphenyl. If the reaction is run at 350° with only a slight excess of alkali the by-products are more plentiful and numerous, the formation of a mixture of dihydroxybiphenyls, cokelike material, and even sodium carbonate having been observed.[5] Heating 5.5 moles of sodium hydroxide and 4 moles of sodium benzenesulfonate to 350° for 5 hours gives among other things 48 g. of phenyl ether and a little thiophenol. To minimize side reactions it is desirable to avoid a local over-concentration of sulfonate. This necessitates adding it in a finely divided condition with stirring. Slow addition of a solution of the sulfonate to the fused alkali has been advocated,[4,10a] as the steam evolved serves to stir the mixture effectively. The formation of phenyl ether is kept at a minimum by adding some of the ether to the fusion mixture.[10b]

$$C_6H_6SO_3Na + C_6H_5ONa \rightarrow (C_6H_5)_2O + Na_2SO_3$$

The phenyl sulfone occurring as a by-product in the preparation of sodium benzenesulfonate is claimed to give a 98% yield of phenol along with 2% of biphenyl when fused with alkali.[9] The presence of sodium *m*-benzenedisulfonate, another sulfonation by-product, is undesirable as this reduces appreciably the yield of phenol, an effect also produced by resorcinol.

Alkylbenzenesulfonic Acids. The presence of one or more alkyl groups in the benzene ring modifies the reaction of an aromatic sulfonate with alkali in two respects. The by-products are increased, the alkyl group in some reactions being oxidized to carboxyl, and the solubility of the sulfonate in the alkali may become so low as to interfere with the reaction. From the data available potassium hydroxide is a better solvent for alkali sulfonates than is the sodium compound, the former even dissolving *p*-cetylbenzenesulfonate.

The *o*- and *p*-toluenesulfonic acids are readily converted to the cresols by potassium hydroxide.[11] A mixture of potassium and sodium hydroxides containing not less than 28% of the potassium compound is also suitable [12] but sodium *p*-toluenesulfonate is not appreciably soluble in sodium hydroxide, hence no reaction occurs. Short heating of the fusion mixture is desirable, and at 330° the evolution of hydrogen begins, indicating oxidation of the methyl group is becoming serious. Graebe and Kraft [13] have observed that if lead dioxide is added to the fusion mixture the methyl group is oxidized to carboxyl, and strangely enough, the sulfo group is replaced by hydrogen. Benzoic acid and a trace of *p*-hydroxybenzoic acid were isolated from the fusion mixture.

In the older literature are to be found brief descriptions of the preparations of many mono,[14] di,[13,15] tri,[16] and tetraalkylphenols [17] which contain only a few points of interest. In practically all of these reactions potassium hydroxide was employed, and it is apparently not known whether the sodium compound could be substituted. Sempotowski [14b] observed that potassium ethylbenzene-4-sulfonate with five parts of potassium hydroxide gives the phenol and *p*-hydroxybenzoic acid, the latter only becoming important after long heating. However, no definite temperature, time, or yields were given. Jacobsen [18] reported that the xylenesulfonic acids give good yields of xylenols with two parts of potassium hydroxide, a hydroxytoluic acid occurring as a by-product from the fusion of the 1,3-xylene-4-sulfonic acid. 2-Methyl-5-isopropylbenzenesulfonic acid gives in addition to carvacrol a small amount of the acid resulting from the oxidation of the methyl group. Whether this is caused by the methyl being adjacent to the sulfonate or the isopropyl being less susceptible to the action of the alkali is uncertain. Mesitylenesulfonic acid[16a] when fused at 285–295° with three parts of potassium hydroxide yields chiefly mesitol while when heated at 240–250° for a longer time[19a] most of the product is 2-hydroxy-3,5-dimethylbenzoic acid. In these fusions the potassium salt of the mesitol separates in a top layer of the reaction mixture at the higher temperatures while at 240–250° the mixture remains homogeneous and oxidation occurs. If lead oxide is added to the fusion mixture the product is benzene-1,3,5-tricarboxylic acid.[13]

Hydroxy acid formation has also been observed in the fusions of 2,4,5-trimethylbenzenesulfonic acid,[16c] 2,3,4,6-tetramethylbenzenesulfonic acid,[17b] and the 2,3,5,6-tetramethyl compound.[17c] The acid from 2-ethyl-3,6-dimethylbenzenesulfonic acid[16e] results from oxidation of the ethyl group while from 2,6-dimethyl-4-ethylbenzenesulfonic acid[16a] is obtained 2-hydroxy-3-methyl-5-ethylbenzoic acid. Pentamethylbenzenesulfonic acid is converted into a mixture of hydroxy acids.[10b]

The action of alkali upon the *p*-cymenesulfonic acids has received more attention than the reactions just described because of the industrial usefulness of thymol and carvacrol. The best set of conditions Gibbs and Phillips found for preparing carvacrol[20] was to heat one-tenth mole of the sulfonate with two moles of sodium hydroxide at 350–360° for 6 hours in an autoclave, the yield being 70%. If the fusion mixture was in contact with the air the yield was reduced to 60%. The presence of water in the mixture also reduced the yield for a given reaction time. Hixson and McKee[21] were able to obtain a 76% yield of a mixture of carvacrol and thymol based on the *p*-cymene sulfonated. Some 6 to 8% of thymol was present in the product. It was noted that some *p*-cymene was given off during the reaction, an observation not so far made for any other alkylated benzenesulfonate. Their results were based upon fusions carried out in an open container.

To obtain appreciable amounts of the sulfonic acid necessary to prepare thymol an indirect synthesis is necessary, but despite this, thymol preparation by this route has received considerable attention.[22] The maximum yield of thymol from the sulfonic acid, amounting to 59% of the theoretical quantity, was obtained by fusing the sodium salt with two or three times its weight of potassium hydroxide at 350° for 30 minutes. Sodium hydroxide gives much poorer results, no yield larger than 15% having been reported.

Closely analogous to the behavior of the dialkylbenzenesulfonic acids is that of 5-indanesulfonic acid. Heating an alkali salt of this with three or four parts of either sodium[23a] or potassium[23b] hydroxide at 290–300° for 45 minutes gives over a 50% yield of the phenol. Similar results have been obtained from tetralinsulfonic acids.[24]

Halobenzenesulfonic Acids. Both halogen atoms and sulfo groups are replaced by hydroxyls when halobenzenesulfonic acids are treated with alkali at a high temperature; the preparation of hydroxysulfonic acids from the corresponding halogen compounds is made possible by a careful regulation of the reaction conditions or by the presence in the molecule of a group which activates the halogen. The synthesis of a halogenated phenol from a halogenated sulfonic acid on the other hand cannot ordinarily be accomplished. The results obtained in a number of reactions support the idea that aqueous alkali is less likely to remove a sulfo group and is therefore to be employed in place of fused alkali for preferential hydrolysis of the halogen. The reactions in which at least one sulfo group is not removed will be considered first.

TABLE IX

HYDROLYSIS WITH 60% POTASSIUM HYDROXIDE

A. Potassium 1-bromobenzene-3,5-disulfonate

		Extent of Hydrolysis	
Time, Hr.	Temp., °C. ± 2	Hal., %	One Sulfo Group, %
3	130	11	2.2
3	130	21	3.1 (trace $CuSO_4$)
2.5	152	61	11.9
0.25	166	35	6.7
1	166	Complete	18.0
2	166	"	19.6
3	166	"	19.8
1	166	"	14.3 (Cu)
B. Potassium 1-chlorobenzene-3,5-disulfonate			
2	166	95	43.3
6	166	Complete	47.7
C. Potassium 1-chlorobenzene-2,4-disulfonate			
0.6	166	82	27.5
3	135	80	29.2
D. Potassium 1-iodobenzene-3-sulfonate			
1	166	10.3	0.4
2	166	30.8	2.9
E. Sodium 1-iodobenzene-3,5-disulfonate			
2	166	95	29
3	130	9.8	2.3

Heating *p*-chlorobenzenesulfonic acid with aqueous sodium hydroxide at 300° for 30 hours has been reported [25] to give phenol-*p*-sulfonic acid. In the hydrolysis of 4-chloro, 4-bromo, and 3,4-dichlorobenzenesulfonic acid the presence of a lead salt and of a catalyst such as copper or copper salts [26] gives increased yields of phenolsulfonic acid. 2,5-Dichlorobenzenesulfonic acid at 170–190° loses the chlorine *ortho* to the sulfo group.[27] Either 3,4-dichlorobenzenesulfonic acid [27b, 28] or 3-chloro-4-hydroxybenzenesulfonic acid [29] when fused with alkali at 250° gives catechol-4-sulfonic acid. The 5-methyl derivative behaves similarly.[30a] 4-Hydroxy-5-chlorobenzene-1,3-disulfonic acid [30b] with aqueous alkali below 200° gives the dihydroxydisulfonic acid.

A quantitative study of the relative rates of hydrolysis for halogen and sulfo groups in a number of halobenzenesulfonic acids with 60% aqueous potassium hydroxide and with the fused alkali gave the results tabulated in Tables IX and X.[31]

From *A*, Table IX, it is apparent that after the bromine has been exchanged for hydroxyl the sulfo group is practically inert to the alkali whereas the halogen is not stabilized by the presence of hydroxyl. The presence of copper or cupric ions apparently increases the rate of hydrolysis for the halogen although the data are too limited to be certain of this. Comparing *B* with *A* indicates that chlorine hydrolyzes more slowly than bromine since over 40% of the first sulfo group is lost before the halogen is completely removed.

TABLE X

HYDROLYSIS WITH FUSED POTASSIUM HYDROXIDE

A. Potassium 1-bromobenzene-3,5-disulfonate

Time, Hr.	Temp., °C. ± 5	Hydrolysis of One Sulfo Group, %
1	200	57.5
3	200	58.2
		59.8
3	255	98
3	300	110

B. Potassium 1-chlorobenzene-3,5-disulfonate

Time, Hr.	Temp., °C. ± 5	Hydrolysis of One Sulfo Group, %
3	200	76
3	260	103
3	310	131

With fused alkali removal of the halogen atom was always complete At 200° or below apparently no sulfo group was removed after all the halogen had been hydrolyzed.

Hydrolysis of the bromine in 4-bromo-3-nitrobenzenesulfonic acid,[32] and the chlorine of 4-chloro-3,5-dinitro-, and 2-chloro-3,5-dinitrobenzenesulfonic acids [33] occurs readily with aqueous alkali, owing to the combined activating influences of the nitro and sulfo groups. A study of the relative activating influences of the nitro, sulfo, and carboxyl groups [34] showed the effect of the nitro group to be of a much higher order than the other two. The sulfo group activates an *ortho* or *para* halogen some three times as much as does carboxyl.

There are a number of instances of the preferential hydrolysis of chlorine from chloronaphthalenesulfonic acids.[35] For example, by the action of an aqueous sodium hydroxide solution upon 4- or 5-chloronaphthalene-1-sulfonic acid, 4-chloronaphthalene-1,6-disulfonic acid, and 4-chloronaphthalene-1,3,6-trisulfonic acid at 200–250° there are produced the corresponding hydroxysulfonic acids.

Reactions other than hydrolysis that involve replacement of the halogen are not numerous. They include the action of potassium phenoxide,[36a] sodium *p*-nitrothiophenoxide, or an aliphatic amine [36c] with a chlorinated sulfonic acid having a nitro or carboxyl group *para* or *ortho* to the chlorine.

In a number of compounds both sulfo and halogen groups have been eliminated completely by treatment with alkali. Where chlorine or bromine is *ortho*, *meta*, or *para* to the sulfonate grouping fusion with alkali always yields resorcinol as the chief product.[37] *p*-Iodobenzenesulfonic acid [38] likewise gives this compound. Similarly both 4-chlorotoluene-5-sulfonic acid [39] and 5-chloro or bromotoluene-3-sulfonic acid [40] yield orcinol when heated at 280–300° with potassium hydroxide. On the other hand 3-bromotoluene-6-sulfonic acid has been reported [41] to yield salicylic acid. 6-Chloro-1,3-xylene-4-sulfonic acid gives the dimethylresorcinol [42] at 230–250°.

Hydroxybenzenesulfonic Acids. *o*-Hydroxybenzenesulfonic acid gives only a small yield of catechol when fused at 330–360° with either sodium [43] or potassium [8,44] hydroxide. Small amounts of resorcinol and hydroquinone have also been separated from the reaction mixture [45a] as well as some 2,4′-dihydroxybiphenyl.[45b] 4-Ethylphenol-2-sulfonic acid [46] with potassium hydroxide gives a mixture of *p*-ethylphenol and 4-ethylcatechol.

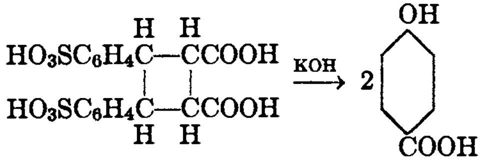
2-Hydroxy-5-chlorobenzenesulfonic acid [47] when treated with potassium hydroxide at 180–190° is reported to give some pyrogallol. The action of alkali upon *p*-hydroxybenzenesulfonic acid does not produce appreciable quantities of hydroquinone. From heating 10 g. of the sulfonate with 7 g. of sodium hydroxide in 50 ml. of water at 300° for 40 hours Willson and Meyer [8] obtained 0.2 g. of phenol and no hydroquinone. 2,4-Dihydroxybiphenyl [48] has been identified as one of the products. Sodium *p*-anisolesulfonate [49] when fused with potassium hydroxide at 280° gives 10% of hydroquinone and 6% of catechol.

As might be expected from the fact that *m*-benzenedisulfonic acid is readily converted to resorcinol, 3-hydroxybenzenesulfonic acid yields the same product.[44b] Resorcinol and hydroquinonesulfonic [50] acids are converted into resorcinol and hydroquinone respectively by heating with potassium hydroxide.

Aminobenzenesulfonic Acids. The behavior of aminosulfonic acids in the benzene series toward alkali fusion has been little studied. Metanilic acid [51] is converted by sodium hydroxide at 280–290° into *m*-aminophenol whereas sulfanilic acid [52] with potassium hydroxide liberates ammonia and at 350–355° a 77% yield of *p*-hydroxybenzenesulfonic acid results. No aniline or potassium sulfite was isolated. 2-Nitroaniline-4-sulfonic acid likewise is readily converted into the nitrophenolsulfonic acid.[53] In 4-nitroacetanilide-3-sulfonic acid the acetamido group is eliminated [54] below 100° with aqueous alkali.

Sulfobenzoic Acids and Derivatives. The three sulfobenzoic acids give rise to the corresponding hydroxybenzoic acids in high yields (90–100%) when fused with potassium hydroxide.[13, 55] The presence of lead dioxide in the fusion mixture has little effect upon the results.[13] 4-Chloro-3-sulfobenzoic acid [56] does not hydrolyze to the dihydroxy acid while for the 5-bromo-3-sulfobenzoic acid [57] such a product is obtained. The alkylated sulfobenzoic acids [58] all react normally except for the 2,4-dimethyl-5-sulfo [59a] and 3,5-dimethyl-4-sulfo [59b] derivatives in which the sulfo substituent is replaced by hydrogen.

When the carboxyl is attached to a side chain as in *m*-sulfophenylpropionic acid [60] the sulfo group is first replaced by hydroxyl and further heating oxidizes the whole side chain down to carboxyl. This occurs even more readily with the sulfocinnamic acids; [61] the intermediate hydroxycinnamic acids have not been isolated. Degradation to *p*-hydroxybenzoic acid likewise occurs when the sulfotruxilic acids [62] are fused with alkali.



The behavior of the sulfohydroxybenzoic acids is comparable to that of sulfonated phenols. 5-Sulfo-2-hydroxybenzoic acid (sulfosalicylic acid) [63] gives a mixture of phenol and salicylic acid, while the 4-sulfo compound with potassium hydroxide at 230–240° yields 2,4-dihydroxybenzoic acid [64] (*β*-resorcylic acid) in a normal manner. Both 4-sulfo-3-hydroxy [65a] and 3-sulfo-4-hydroxybenzoic [65b] acid give the dihydroxy acid, although from the former compound another acid is also produced. The chlorine of 3-chloro-4-hydroxy-5-sulfobenzoic acid is removed preferentially by potassium hydroxide[66a] at 180°. 4-Methoxy-3-sulfobenzoic acid with potassium hydroxide loses the methyl as well as the sulfo group to give the dihydroxy compound.[66b]

The sulfonated di[59a,67] and tricarboxylic[58,68] acids react normally in every reaction.

Benzaldehydesulfonic Acids. When benzaldehyde-*o*-sulfonic acid is heated with aqueous potassium hydroxide under pressure[69] at 220–240° the products are benzoic and salicylic acids. Benzaldehyde-*p*-sulfonic acid reacts similarly while for the *meta* isomer only the hydroxy acid has been reported.[70]

Benzenedisulfonic Acids. (See also p. 424.) Barth and Senhofer[44b] were responsible for demonstrating that it is possible to remove one of the sulfo groups from *m*-benzenedisulfonic acid without affecting the other. Heating the potassium salt with two to three times its weight of potassium hydroxide and a little water at 170–180° for 1 hour gives the hydroxysulfonate. With 10% aqueous sodium hydroxide at 250° a 78% yield of the hydroxysulfonate results after 30 hours.[8] The much higher temperature needed under these conditions is noteworthy. Isolation of the product is somewhat difficult as its solubility behavior is similar to that of the inorganic salts present after neutralizing the reaction mixture. It was known considerably earlier[71] that fusion of the disulfonic acid with an excess of sodium hydroxide at 270° or above gave resorcinol. Two procedures for carrying out the reaction may be mentioned. Using two to two and one-half moles of sodium hydroxide per sulfonate group and heating the fusion mixture in thin layers to 300–425° on sheet metal[72] is claimed to give good results. If the customary fusion apparatus is employed, seven moles of alkali to one of the sodium benzenedisulfonate is necessary unless a stirrer is used when it may be reduced to five. Holding the temperature first at 300–310° then raising to 318–320° gives best results.[73] The resorcinol was isolated by extracting the acidified fusion mixture with an ether-benzene mixture.

Little study has been made of the fusion reactions of disulfonic acids where the two groups are other than *meta* to each other. Garick[74] reported that *p*-benzenedisulfonic acid was converted into resorcinol by treatment with fused sodium hydroxide.

Alkylbenzenedisulfonic Acids. In the fusion of toluene-2,4-disulfonic acid with alkali at 200° the sulfo group *ortho* to the methyl is removed.[75] Higher temperatures produce 4-methylresorcinol.[76] Toluene-3,5-disulfonic acid is readily converted to orcinol.[77] *m*-Xylene-

2,4-disulfonyl chloride with potassium hydroxide gives the corresponding dimethylresorcinol.[78] The 6-chloro and 6-bromo derivatives of this are converted into the corresponding halodimethylresorcinol,[78a] a result entirely unexpected in view of the behavior of other halogenated sulfonic acids. It is reported that mesitylenedisulfonic acid [78c] when heated with potassium hydroxide at 250° forms 2-hydroxymesitylenic acid quantitatively.

Phenoldisulfonic Acids. The reactions of chlorophenoldisulfonic acids have been mentioned under the preparation of hydroxysulfonic acids. Phenol-2,4-disulfonic acid [79] with either sodium or potassium hydroxide yields a mixture of catechol and catechol-4-sulfonic acid. It has been reported [80a] that resorcinol-4,6-disulfonic acid reacts with potassium hydroxide to give phloroglucinol in small yield. The main products, however, are resorcinol and resorcinol-4-sulfonic acid.[80b]

Anilinedisulfonic Acid. Aniline-2,5-disulfonic acid,[80c] obtained by sulfonation of metanilic acid, when fused with sodium hydroxide yields 3-aminophenol-4-sulfonic acid.

Disulfobenzoic Acids. It is possible to replace either one [81] or both [82] of the sulfo groups of 3,5-disulfobenzoic acid without removing the carboxyl. Adams and Graves [83a] obtained a 30% yield of the dihydroxy acid by fusing the sulfonate with potassium hydroxide for 8 hours at 250°. The yield was much improved [83b] by fusing the barium salt with a mixture of sodium and potassium hydroxides at 290–310°. These results have been confirmed.[84] A 63% yield of the dihydroxy compound was readily isolated. The ready availability of this acid is of importance in the preparation of various naturally occurring 5-substituted resorcinols. It should be mentioned that the second step in the fusion reaction, the conversion of 3-sulfo-5-hydroxybenzoic acid into the dihydroxy compound, has been described.[85]

2,4-Disulfobenzoic acid [86a] as well as the isomeric methyl-3,5-disulfobenzoic acids [86b] have also been converted to the corresponding dihydroxy compounds.

Benzene- and Phenoltrisulfonic Acids. The behavior of *sym*-benzenetrisulfonic acid toward fused alkali at various temperatures has received considerable study. Senhofer [87] showed that at 150° one sulfo group is replaced, the second coming off at 240°. Since the dihydroxysulfonic acid is quite stable careful regulation of the temperature used in its preparation is not important, anywhere in the range 240–260° being suitable.[88] Best results are obtained when the sodium benzenetrisulfonate is fused with six times its weight of sodium hydroxide. Less alkali gives a mixture of products from which none of the dihydroxy compound could be isolated. Barth and Schreder [89] reported that fusion of the trisulfonate with sodium hydroxide for 10 minutes produces a 25–30% yield of phloroglucinol. Since these investigators did not specify the temperature or ratio of reactants it is not possible to duplicate their experiment exactly but recently it was found [88] that when heated with three times its weight of sodium hydroxide at 335° the sulfonate gave no appreciable amount of phloroglucinol for either a 10-minute or 1-hour reaction period. It is probable that other unreported attempts to duplicate Barth and Schreder's experiment have been made without success as it offers a possibility of obtaining phloroglucinol cheaply.

Phenol-2,4,6-trisulfonic acid with potassium hydroxide gives catechol-4,6-disulfonic acid,[90] which by acid hydrolysis yields catechol. Alkali completely decomposes trisulfo-*m*-hydroxybenzoic acid.[91]

Biphenylsulfonic Acids and Other Polyring Acids. The conversion of sulfonated biphenyls into the corresponding hydroxy compounds offers little that is novel. 4-Hydroxybiphenyl [92] and several dihydroxybiphenyls [93] have been prepared from the sulfonic acids as has a 4-methoxyhydroxybiphenyl of uncertain structure.[94] 4,4′-Dihydroxybiphenyl-2,2′-disulfonic acid [95] and the 3,3′-dihydroxy-4,4′-disulfonic acid [96] are reported to give the corresponding tetrahydroxybiphenyls. A dibenzyldisulfonic acid gives with fused potassium hydroxide [97] first the mono, then the dihydroxy compound together with some *p*-hydroxybenzoic acid. This last product indicates the structure of the original acid. On the other hand all benzophenonesulfonic acids are completely split into compounds containing a single ring. The 2-sulfonic acid [98] yields benzoic acid and benzenesulfonic acid while for the 3,3′-disulfonic acid only 3-hydroxybenzoic acid has been isolated.[99] *p*-Toluic acid was the only identified product resulting from 4-methylbenzophenone-2′-sulfonic acid.[100] The behavior of benzophenone derivatives makes that of fluorenesulfonic acids understandable.[101] Not only is a sulfo group replaced but also the methylene is oxidized to a ketone linkage, the final product being a hydroxybiphenylcarboxylic acid. *sym*-Tetraphenylethanetetrasulfonic acid [102] and also the tetraphenylethylene [103] derivative have been reported to give tetrahydroxy compounds when fused with potassium hydroxide.

Naphthalenesulfonic Acids. The two naphthalenesulfonic acids [104] are readily converted into the corresponding naphthols by fusion with three parts of sodium or potassium hydroxide at 300–320°. The sodium naphthoxide separates out as a layer on the fused sodium hydroxide. Naphthalene is a by-product of the reactions.[105]

$$C_{10}H_7SO_3Na + NaOH \rightarrow C_{10}H_8 + Na_2SO_4$$

The naphthols have likewise been obtained by heating the sulfonates to 300° with 10% aqueous sodium hydroxide.[8] It has been noted [7] that hydrogen is evolved from the fusion mixture of the β-sulfonate when the reaction is carried out in contact with the air but is not formed in a nitrogen atmosphere. Hence a closed container is advantageous in preventing side reactions.

Derivatives of Naphthalenesulfonic Acids. Many complex naphthol derivatives that are of value as dye intermediates have been prepared by treating the readily obtainable sulfonic acids with alkali at a high temperature. Most of the descriptions of the procedures employed are given only in the older patent literature and lack the reliability that might be desired. However, a few conclusions may be drawn regarding the effect of substituents and the location of the sulfo group upon the manner in which reactions proceed. In general α-sulfonic acids are more reactive toward alkali than are the β-compounds.[106] As in the benzene series an amino group *para* to the sulfonic acid substituent is removed as ammonia whereas the *m*-amino group is unaffected. The amino group is also activated when in the *peri* position. For the β-naphtholsulfonic acids the reaction with alkali requires a much higher temperature for the 6-sulfonic acid than for the 7-isomer. This is not surprising because the 6-position here is analogous to the *para* position in the phenol nucleus and it is only at a high temperature that a phenol-*p*-sulfonate reacts with fused alkali.

Conversion of alkylnaphthalenesulfonic acids into the naphthols has been investigated only occasionally. 1-Methylnaphthalene-4-,[107] 6-, and 7-sulfonic acids [108] and the 2-methylnaphthalene-6- and 8-sulfonic acids [109] have been converted into the methylnaphthols by potassium hydroxide. 1-Benzylnaphthalene-4-sulfonic acid [110] and several dimethylnaphthalenesulfonic acids [111] have been similarly treated. No mention was made of the alkyl groups undergoing oxidation by the alkali.

Many reactions in which hydroxynaphthalenesulfonic acids have been converted into the dihydroxy compounds are on record [112] without an abnormal reaction occurring. 1,6-Dihydroxynaphthalene-3-sulfonic acid yields the trihydroxy compound [113] below 270°.

As in the benzene series, sulfonaphthalenecarboxylic acids are converted into hydroxy compounds without affecting the carboxyl group.[114] This is also true for hydroxysulfocarboxylic acids [115] and sulfodicarboxylic acids [114f, 116] except for 2-sulfo-1,8-naphthalic acid which is converted by fused sodium hydroxide into 7-hydroxynaphthoic acid. However at 150° with potassium hydroxide both carboxyls are retained. The 4-sulfo-1,8-naphthalic acid reacts similarly.[116d,e] 1-Cyanonaphthalene-8-sulfonic acid [117] when heated with alkali in alcohol solution yields 1-aminonaphthalene-8-carboxylic acid, the ammonia from the cyano group replacing the sulfur.

The behavior of aminonaphthalenesulfonic acids is variable and dependent upon the structure, upon the concentration of the alkali employed, and upon the reaction temperature. A comprehensive investigation of the reactions that a variety of amino acids undergoes with aqueous sodium hydroxide of various concentrations has been reported by Fierz.[118] A mixture of compounds always resulted, because of the occurrence of simultaneous and consecutive reactions. These were: replacement of the sulfo group by (1) hydroxyl, or (2) hydrogen, and (3) replacement of the amino group by hydroxyl. Thus 1-aminonaphthalene-4-sulfonic acid (naphthionic acid) yields varying amounts of 1-naphthol and 1-naphthol-4-sulfonic acid together with a trace of 1,4-dihydroxynaphthalene, but no aminonaphthol. On the other hand, 1-aminonaphthalene-8-sulfonic acid gives chiefly the dihydroxynaphthalene, 1-naphthylamine, and smaller amounts of 1-naphthol-8-sulfonic acid and 1-amino-8-naphthol. For the 1-aminonaphthalene-5-sulfonic acid the results are still different, the dihydroxy and aminohydroxy compounds predominating, up to 8% of naphthylamine and no more than a trace of 1-naphthol-5-sulfonic acid being isolated. The 1-aminonaphthalene-6-sulfonic acid when heated to 260° with 50% sodium hydroxide for 3 hours gives rise to more of a naphtholsulfonic acid, believed to be the 1,5-compound, than anything else. The dihydroxynaphthalene, naphthylamine, and aminonaphthol were present in lesser amounts. The 1,7-aminosulfonic acid under the same conditions is converted into equal amounts of the 1-naphthol-7-sulfonic acid and the aminonaphthol, together with a trace of dihydroxy compound. For further details the original must be consulted.

With fused alkali aminonaphthalenesulfonic acids show less tendency to exchange the amino groups for hydroxyls than in aqueous solution. Thus 1-aminonaphthalene-3-,[119] 5-,[120] 7-,[121] and 8- [122] sulfonic acids have been converted to the aminonaphthols while the 4-sulfonic acid still loses the amino group first. 2-Aminonaphthalene-7-sulfonic acid also yields the aminonaphthol.[123] In the case of 1-amino-8-chloronaphthalene-4-sulfonic acid it is claimed [124a] that the chlorine is preferentially eliminated. 1,8-Diaminonaphthalene-4-sulfonic acid [124b] and 1-amino-8-naphthol-4-sulfonic acid both yield the 1,8-dihydroxysulfonic acid with loss of ammonia. Loss of the 1-amino group might be expected; the loss of the 8-amino group before the sulfo substituent is affected is due to the stabilizing action of the hydroxyl on the sulfur-carbon bond.

Conversion of naphthalenedisulfonic acids to the dihydroxy compounds [125] occurs without rearrangement. However, naphthalene-1,3-disulfonic acid [126] and its substitution products may be broken down to toluic acid derivatives and acetic acid or yield a trihydroxynaphthalene. As with benzene derivatives it is usually possible to remove one sulfo group to give a hydroxy sulfonic acid. This has been reported for naphthalene-1,5-,[127] -2,6-,[128] and -2,7- [129] disulfonic acids.

2-Hydroxynaphthalene-3,6-disulfonic acid with dilute alkali is converted into 2,3-dihydroxynaphthalene,[130] one sulfonic acid group being replaced by hydroxyl and the other by hydrogen. Other hydroxynaphthalenedisulfonic acids act normally,[130c, 131] one sulfo group undergoing replacement by hydroxyl. Apparently no trihydroxynaphthalene has been made by this reaction. However, the 1,8-dihydroxy-3,6-disulfonic acid [132] yields 1,3,8-trihydroxynaphthalene-6-sulfonic acid readily. 1-Hydroxy-4,7-disulfo-2-naphthoic acid [133] has been reported to lose the carboxyl and the 7-sulfo group is replaced by hydroxyl when the compound is heated with aqueous alkali. Several other hydroxydisulfonaphthoic acids [134] have been converted into dihydroxysulfonaphthoic acids.

The behavior of the aminodisulfonic acids is complicated because either the amino or one or both sulfo groups may be replaced by hydroxyl. It seems highly probable that in every reaction more or less complicated mixtures result. The inadequacy of the older patent literature on this point makes it unwise to attempt to draw conclusions from the results reported. The number of aminodisulfonic acids which yield aminonaphtholsulfonic acids is, however, large [135] and several of the latter are important dye intermediates. There are also at least two instances of dihydroxynaphthalenesulfonic acids resulting.[136] Here the amino group is *para* to one of the sulfo substituents and reacts as it does in naphthionic acid. Ammonia is also lost from 8-amino-1-naphthol-2,4-disulfonic acid, the -5,7-disulfonic acid,[137] and from the 4,6-disulfonic acid [138] by treatment with hot aqueous sodium hydroxide. On the other hand 2,3-diaminonaphthalene-6,8-disulfonic acid loses the 8-sulfo group [139] and also one sulfo group of the 1,5-diamino-3,7-disulfonic acid is replaced.[140]

The action of alkali upon naphthalenetrisulfonic acids leads to replacement of one [141] or two [142, 143] sulfo groups by hydroxyl but the trihydroxy compound reacts further to yield a hydroxytoluic acid if two of the hydroxyls are *meta*. The occurrence of rearrangements in these reactions has not been studied. 2-Hydroxynaphthalene-3,6,8-trisulfonic acid[144] gives a mixture of dihydroxydisulfonic acids while for the 1-hydroxy-2,4,8-[145] and -3,6,8-trisulfonic[144,146] acids the 8-sulfo group is replaced. In the latter compound the 3-substituent may also be forced to react.[147] What is believed to be the 1-hydroxy-3,5,7-trisulfonic acid[148] reacts with alkali first in the 3-position. Both the 3- and 5-sulfo groups of 2-hydroxy-3,5,7-trisulfonic acid[149] have been replaced by hydroxyls.

The 1-aminonaphthalene-2,5,7-[150] and 3,5,7-[151] trisulfonic acids and the 2-amino-2,5,7-acid[152] readily exchange the 5-sulfo group for hydroxyl whereas the 1-amino-3,6,8-[144,153] and -4,6,8-[154] trisulfonic acids lose the 8-sulfo group easily. As might be expected the *peri*sultam of the 1-amino-2,4,8-trisulfonic acid[145,155] loses ammonia and also the 8-sulfo group. However, by varying the reaction conditions the hydroxyl may be introduced in the 8-position without loss of ammonia.[156] This is analogous to the behavior of 1-amino-2,4,6,8-[157] and -3,4,6,8-tetrasulfonic acids[145] which also undergo replacement of the 8-sulfo groups.

Anthracenesulfonic Acids. The anthracene-1- and -2-sulfonic acids are converted into the hydroxyanthracenes (anthrols) by a fusion with potassium hydroxide[158] at 180–300° or by treatment with strong aqueous sodium hydroxide[159] in an autoclave at 230–290°, the required temperature depending upon the compound and the amount of water present. As for the naphthalenesulfonic acids the 1-sulfo group is the more reactive and the more dilute the aqueous alkali the higher must be the temperature to complete the reaction in a given time. Yields of 95–98% of the anthrol were obtained when the 1-sulfonic acid was heated with an equal weight of potassium hydroxide and twice its weight of water for 7 hours at 230°. When sodium hydroxide was used the heating required was 10 hours at 240°. Heating the 2-sulfonic acid with three parts of sodium hydroxide and three of water at 290° from 4 to 5 hours was found to give the best results;[159] with the potassium hydroxide a temperature of 270° was sufficient. Anthracenedisulfonic acids upon fusion with potassium hydroxide give first hydroxysulfonic acids then dihydroxyanthracenes.[160] 9,10-Dihydroanthracene-2-sulfonic acid with alkali goes over to anthracene and dihydroanthracene.[161]

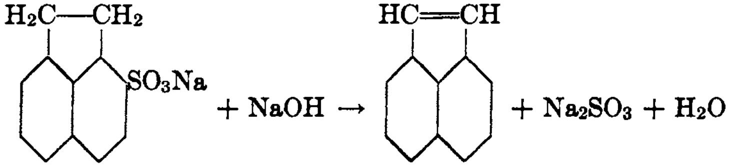
Anthraquinonesulfonic Acids. The conversion of anthraquinonesulfonic acids into alizarin and other dyes by the action of fused alkali has received detailed investigation because of its technical importance. Sulfonated anthraquinones are converted into hydroxy compounds at a lower temperature than are the anthracene derivatives. Anthraquinone-1-sulfonic acid is hydrolyzed by aqueous sodium carbonate [162] at 200° while with aqueous sodium hydroxide reaction occurs at a lower temperature.[162a, 163] Calcium or barium hydroxide solutions at 180–200° bring about the same change without the occurrence of ring-splitting or oxidation, side reactions noticeable when alkali hydroxides are employed. Anthraquinone-2-sulfonic acid is converted to the hydroxy compound at 160–165° with 20% sodium hydroxide [164] or dilute calcium or barium hydroxide.[162a, 163] Fusion with sodium hydroxide brings about the well-known conversion to alizarin, a reaction which is, however, not complete [165] unless carried out in the presence of oxidizing agents such as potassium nitrate or chlorate.[166] Fusion of anthraquinone-2,6- or 2,7-disulfonic acid with sodium hydroxide gives a little of the dihydroxyanthraquinone but the main product is a trihydroxy derivative,[167] the 2,6-acid giving the 1,2,6-trihydroxy compound (flavopurpurin), the 2,7-acid being converted into the 1,2,7-trihydroxyanthraquinone (anthrapurpurin). When 2-hydroxyanthraquinone-3-sulfonic acid is heated with sodium hydroxide to 190° the alizarin-3-sulfonic acid results, a case of oxidation without accompanying replacement of the sulfo group.[168] In general hydroxyanthraquinonesulfonic acids, unlike analogous compounds in the benzene series, have their sulfo groups readily replaced by hydroxyl even when the resulting compound has two such groups *ortho* to each other.[169] Most of the complex hydroxy compounds useful as dyes which have been obtained from sulfonic acids have been prepared by heating the sulfonates with aqueous alkali under pressure, the base most frequently being that of an alkaline earth metal.[170]

Phenanthrenesulfonic Acids and Derivatives. When the potassium [171] or barium salt [172] of phenanthrene-2- or -3-sulfonic acid is fused with three times its weight of potassium hydroxide at 300–325° it was found possible to isolate a 72% yield of the pure phenanthrol. The results obtained with a mixture of phenanthrenedisulfonic acids were even more satisfactory.[173] Although no proof is available, it is unlikely that rearrangements occurred in these reactions as rearrangements are usually limited to reactions where the replaced groups are *ortho* or *para* to one another in the same aromatic ring. The disulfonation of a compound containing two rings which substitute with equal ease never leads to the introduction of both sulfo groups into one ring in more than traces.

The monosulfonic acids derived from retene have likewise been converted to hydroxy compounds by fusion with potassium hydroxide.[174] Phenanthrenequinone-3-sulfonic acid has been reported [175] to give

3-phenanthrol when fused with potassium hydroxide while with a 50% aqueous solution phenanthrene-3-sulfonic acid and fluorenone are produced.

Sulfonic Acids of Miscellaneous Cyclic Compounds. The abnormal behavior of acenaphthene-3-sulfonic acid is noteworthy;[176] alkali fusion yields acenaphthylene.



When fluorene-2,7-disulfonic acid is treated with fused alkali the methylene group is oxidized[177] and hydrolyzed to carboxyl as well as the sulfo groups being replaced by hydroxyl.

Several hydroxy derivatives of heterocyclic compounds have been prepared from sulfonic acids but these, except for an acridine derivative, are polycyclic compounds in which the sulfo group is attached to a homocyclic ring. Thus quinoline-8-sulfonic acid yields the hydroxy compound when heated with aqueous sodium hydroxide under pressure[178] at 180°. Carbazole-2,3,6,8-tetrasulfonic acid when heated at 200° with sodium hydroxide loses the 2-sulfo group whereas at higher temperatures[179] hydroxyls are introduced at both the 2- and 8-positions. Previously it had been claimed[180] that one hydroxyl was introduced into the 2,7-disulfonic acid by alkali at 270–290°.

The sulfonic acids obtained from acridine by reaction with sulfurous acid or sodium bisulfite are reconverted into acridine by treatment with alkali.[181]

REPLACEMENT OF THE SULFO BY THE AMINO GROUP

Reaction with Sodamide. As might be anticipated, because of the analogy between the water and ammonia systems, sodamide reacts with sulfonic acid salts to give amines. Likewise just as a by-product in a fusion of an alkali benzenesulfonate with sodium hydroxide is phenyl ether, with sodamide diphenylamine results.

Heating potassium benzenesulfonate[182] with sodamide gives only about a 10% yield of aniline together with a little diphenylamine, but if naphthalene is added to the mixture[182b] the yield is raised to about 30% when the temperature is 160°. It was suggested[182a] that the formation of diphenylamine occurred because of the presence of some disodamide (Na_2NH) in the reagent, but it seems just as reasonable that sodanilide ($NaNHC_6H_5$) from sodamide and aniline was responsible.

$$C_6H_5SO_3K + C_6H_5NHNa \rightarrow (C_6H_5)_2NH + NaKSO_3$$

Only a trace of *m*-phenylenediamine was obtained from sodium *m*-benzenedisulfonate[182a] and phenol-*p*-sulfonic acid gave no aminophenol.[182b] The results obtained in the naphthalene series have been much more favorable. While sodium β-naphthalenesulfonate gave only 32% of β-naphthylamine, 2-naphthol-6-sulfonic acid yields as high as 51% of the aminonaphthol. In the most favorable experiment 50 g. of the sulfonate, 75 g. of sodamide and 60 g. of naphthalene were heated for 40 minutes at 230–240°. Technical 2-naphthol-7-sulfonic acid gave 57% of a complex mixture of aminonaphthols from which some 1-amino-6-naphthol was isolated in addition to the expected product.[183] 2-Naphthol-8-sulfonic acid gave similar results[182b] while from 2-naphthol-1-sulfonic acid a 60% yield of an aminonaphthol of undetermined structure was obtained.

1-Naphthol-5- and 8-sulfonic acids[184] are converted into aminonaphthols but no definite product could be obtained from naphtholdisulfonic acids. Sodium anthraquinone-2-sulfonate gives a violent reaction with sodamide at 200° but the yield of amine isolated was negligible.

Reaction of Ammonia. If the sulfo group is activated as in 2,4-dinitrobenzenesulfonic acid, heating with ammonia in a sealed tube readily[185] gives the amine. There are also several instances in the naphthalene and anthraquinone series where sulfo groups have been found to be replaceable by heating with ammonia. Naphthalene-1,3,5-trisulfonic acid when heated with ammonia and sodium hydroxide[186] under pressure is converted to 1,3-diaminonaphthalene-5-sulfonic acid. Here the sulfo groups may first be replaced by hydroxyls but this could hardly be true for the action of ammonia and ammonium chloride[187] on 1-aminonaphthalene-3,6-disulfonic acid or the corresponding hydroxydisulfonic acid which both yield 1,3-diaminonaphthalene-6-sulfonic acid. The 1,3-diamino-8-sulfonic acid has been similarly obtained.[188] 1-Naphthol-3,5,7- and 3,6,8-trisulfonic acids[189] are converted to the 1,3-diaminodisulfonic acids by the ammonia-ammonium chloride treatment.

In the anthraquinone series it has been found that the 1-[190] and 2-[191] sulfonic acids and the 2,6-disulfonic acid[192] are converted into the corresponding amino compounds by heating with ammonia in water solution under pressure at 180°. Under these conditions the

2,7-disulfonic acid gives chiefly the aminosulfonic acid, only one sulfo group undergoing replacement.[191a,193] This aminosulfonic acid when autoclaved with 27% ammonia and arsenic acid at 180° for 24 hours gives the diamino compound.[194] Quantitative data for the reaction of the anthraquinone mono- and disulfonic acids with ammonia have been reported by Lauer.[195] The addition of disodium arsenite to the reaction mixture apparently facilitates the replacement, a 92–94% yield of 2-aminoanthraquinone having been reported for a reaction in which this salt was added.[196] Presumably also the reaction is aided by the presence of sodium dichromate[197] but the maximum yield reported after a systematic study[198] was 63% of the theoretical amount.

REPLACEMENT OF THE SULFO GROUP BY CARBOXYL

Reaction with Sodium Formate. The discovery that heating sodium formate alone gave hydrogen and sodium oxalate indicating the momentary existence of a free carboxyl group led Meyer[199] to investigate the behavior of salts of sulfonic acids when heated with this compound. Sodium benzenesulfonate was found to be too high melting to enter into a reaction, but the potassium salt gave sodium benzoate readily although in low yield. This reaction was then applied by Meyer and others to sulfonates derived from a number of alkylbenzenes[200] and naphthalene[201] with similar results. Usually the yield of acid has not been reported, but judging by the results obtained with sodium naphthalene-1-sulfonate[201] it is in the neighborhood of 5 to 10%. The *m*- and *p*-sulfobenzoic acids[199,202] yield iso- and terephthalic acids respectively and the reaction also works for 4-sulfo-3-methylbenzoic acid[203] and toluene-2,4-disulfonic acid,[204] but sulfoterephthalic acid[205] is reduced to terephthalic acid and sodium sulfite while 4-bromo-3-sulfobenzoic acid[206] and the chlorine[207] compound give a mixture of isophthalic, terephthalic, and benzoic acids but no trace of the tricarboxylic acid. The reducing action of the sodium formate also functions when *p*-chlorobenzoic acid is fused with it, benzoic acid resulting.[199] The tricarboxylic acid was likewise not obtained when 3,5-disulfobenzoic acid[208] was fused with potassium formate, the sole acid isolated being isophthalic, but 5-sulfoisophthalic acid does give the tricarboxylic acid.[209]

Reaction with Alkali Cyanides and Ferrocyanides. A more satisfactory method for converting sulfonic acids into carboxylic acids than by fusion of the sulfonates with sodium formate is to convert them first into the cyanides and then to hydrolyze. The yield of cyanide varies from a trace for some of the substituted sulfonic acids to about 50%

with the naphthalenesulfonic acids. Most investigators who have compared an alkali cyanide with potassium ferrocyanide in this reaction prefer the latter because of the better yields as well as its low toxicity. Success in carrying out the reaction depends upon having the reactants dry and intimately mixed and employing a container such that the whole mass may be brought to a high temperature. A piece of iron pipe with proper fittings has been used with good results. At least a 100% excess of cyanide is advantageous.

The preparation of benzonitrile by heating potassium benzenesulfonate with potassium cyanide [210] and with potassium ferrocyanide [211] has been mentioned but not thoroughly investigated. 3-Chloro [212] and 3-bromobenzenesulfonic [213] acids give low yields of isophthalonitrile while for the *para* isomers [214] up to 20% of terephthalonitrile results if the mixture is distilled in 10-g. portions. Refluxing potassium *m*-nitrobenzenesulfonate [215] with aqueous potassium cyanide gives a complex mixture of sulfonated carboxylic acids.

Ortho and *p*-toluenesulfonic acids [215,216] and *p*-cymenesulfonic acid [217] with potassium cyanide give small yields of the nitriles. Heating three parts of potassium 1-naphthalenesulfonate [211,218] with two parts of potassium ferrocyanide gives a 50% yield of crude 1-naphthonitrile containing some naphthalene. Ammonium carbonate is also formed in large quantities. Results comparable to these have been obtained more recently by distilling equimolecular amounts of the sodium sulfonate and sodium cyanide.[219] From distilling 1 kg. of sodium 2-naphthalenesulfonate with one-half its weight of 70% potassium cyanide (the remainder was mostly potassium cyanate) the yield of crude (80–90%) nitrile was reported [220] to be 410 g. Other products noted were naphthalene, water, hydrogen sulfide, ammonium carbonate, and ammonium cyanide. Increasing the amount of cyanide increased the yield only slightly. The yield was a little better when the potassium sulfonate was utilized and poorer with the calcium salt. It has also been claimed [221] that the yield is higher when potassium ferrocyanide is used.

Potassium biphenyl-4-sulfonate is converted into the nitrile in fair yields by heating with either potassium cyanide [222] or ferrocyanide.[223] In the latter reaction after hydrolysis there was obtained 100 g. of 4-phenylbenzoic acid from 300 g. of biphenyl used as the starting material.

Potassium 1-,[224] 2-,[225] 3-,[225,226] and 9-[226b,227] phenanthrenesulfonates have been converted into the nitriles in yields of approximately 40% or better by distilling with potassium ferrocyanide.

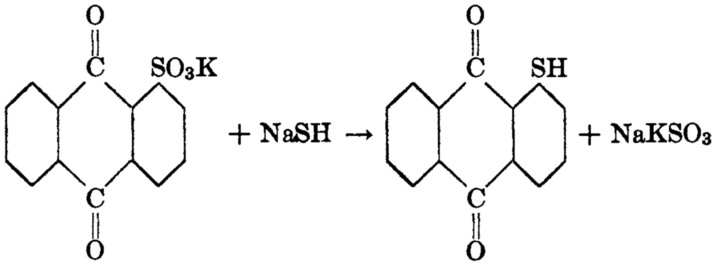
From heating potassium acenaphthene-3-sulfonate with potassium ferrocyanide [228] acenaphthylene results.

A number of disulfonic acids has been converted into dinitriles but the yields are somewhat less than obtained with the monosulfonic acids. Potassium benzene-*m*-disulfonate [214a, 229] when heated with potassium cyanide gives a 15% yield of the crude dinitrile. The 1,4-disulfonate has likewise been utilized in this reaction.[214a, 229b, 230] Considerably better results (25–40% yields) have been obtained from potassium naphthalene-2,7-disulfonate [231] than from the 2,6-isomer (10–14% yields) but this may have been due to a difference in reaction conditions. Distillation of potassium biphenyl-4,4′-disulfonate with potassium cyanide in a stream of carbon dioxide gives a lower yield of the nitrile [232] than was obtained in the case of the monosulfonate.[222] A potassium pyrenedisulfonate [233] behaves anomalously in that a mixture of pyrene mono- and dinitriles is formed.

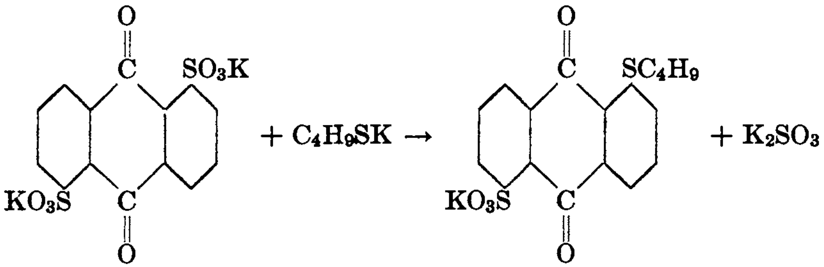
One other reaction may be mentioned. Jackson and Wing reported that potassium benzenetrisulfonate upon distillation with potassium cyanide gives some of the nitrile of trimesic acid.[234]

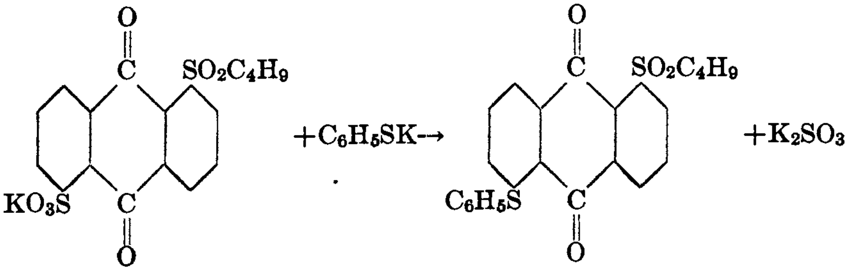
Replacement of Sulfo by Sulfhydryl and Sulfide Groups

Reaction with Alkali Hydrosulfide. From analogy one would expect potassium hydrosulfide to react with the salt of a sulfonic acid just as does potassium hydroxide. While this reaction has not been studied comprehensively it appears that the yields are too low for it to have much practical interest. Stadler [235] observed that the dry distillation of sodium benzenesulfonate and potassium hydrosulfide under reduced pressure gives some thiophenol. If a saturated solution of the sulfide is used and the mixture heated under pressure at 275° for 3 hours [236] a brown dye is the chief product, only a trace of a thiol being formed. Neither here nor in the reaction of *m*-benzenedisulfonate was the chief product identified. Sodium 2-naphthalenesulfonate was converted into a mixture of 2-naphthol, 2-thionaphthol, and the disulfide. The yield of thionaphthol was found to be unusually variable for no apparent reason. When potassium sulfide was present the yield of 2-naphthol was increased. If the sulfo group is activated as in 2,4-dinitrobenzenesulfonic acid, however, the reaction with aqueous potassium hydrosulfide occurs at room temperature [237] to give 2,4-dinitrothiophenol. Anthraquinone-2-sulfonic acid [238] is nearly as reactive, the potassium salt undergoing double decomposition with sodium hydrosulfide in aqueous solution at the boiling point.



Reaction with Salts of Thiols. The reactivity of the anthraquinonesulfonic acids toward sodium hydrosulfide suggests that they would also react with thiols in aqueous alkaline solution. It was first observed that heating potassium anthraquinone-1-sulfonate with potassium thiophenoxide does give the anthraquinonyl phenyl sulfide,[239] but this does not occur at 100° in water solution.[240] On the other hand, the aliphatic thiols react readily with both mono- and disulfonates having the sulfo groups in the alpha position[241] at as low a temperature as 60°. The intermediate in the reaction of the 1,5-disulfonate is so slightly soluble in water that it is easy to stop the reaction with only one sulfo group replaced, while for the 1,8-compound the monosulfonate stays in solution. The sulfonate group in the intermediate becomes particularly active when the sulfide is oxidized to the sulfone, reacting with boiling aqueous thiophenoxide solution.[240b]

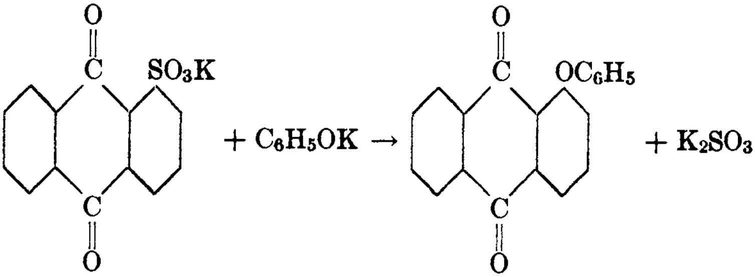




MISCELLANEOUS REPLACEMENT REACTIONS

In a brief report Armstrong[242] gives the results of distilling potassium 1- and 2-naphthalenesulfonates with potassium thiocyanate. The most prominent product in each case was the disulfide. In addition some naphthalene was noted. The investigation was discontinued and apparently the reaction has not been further studied.

The anthraquinonesulfonic acids have been observed to undergo replacement reactions other than those already mentioned. Thus either the 1-[243] or 2-[244] sulfonic acid when heated with methyl alcohol and alkali under pressure yields the methyl ether, and the 1,5-disulfonic acid is converted to the diether.[243] Similar reactions occur with potassium phenoxide[245] and the 1-[246] and 2-[247] naphthoxides at about 170°.



That potassium thiophenoxide behaves in the same manner has already been mentioned. Ether formation from more complex anthraquinone derivatives, the 1-amino-4-arylsulfonamidoanthraquinone-2-sulfonic acids, which yield ethers with alcohols and alkali has been described in the patent literature.[248]

Heating anthraquinone-2-sulfonic acid with an oxidizing agent in sulfuric acid does not affect the sulfo group; hydroxyanthraquinonesulfonic acids are, however, produced.[249]

REFERENCES FOR C. REACTION OF METAL SULFONATES WITH BASES AND SALTS

1. Limpricht, *Ann.*, **177**, **72** (1875).

2*a*. Willgerodt and Mohr, *J. prakt. Chem.*, [2] **84**, 116 (1886). *b*. Bender, *Ber.*, **28**, 422 (1895); Green and Baddiley, *J. Chem. Soc.*, **93**, 1722 (1908), and other articles by Green and co-workers. *c*. Kalle and Co., German pat., 138,188, *Chem. Zentr.*, I, 371 (1903).

3. Wurtz, *Compt. rend.*, **64**, 749 (1867); Kekulé, *ibid.*, **64**, 752 (1867); Dusart, *ibid.*, **64**, 759 (1867).

4. For a discussion of the engineering aspect of the reaction see Peterkin, *Ind. Eng. Chem.*, **10**, 738 (1918); Ney and Van Marle, *Met. Chem. Eng.*, **16**, 217 (1917).

5. Rhodes, Jayne, and Bivins, *Ind. Eng. Chem.*, **19**, 804 (1927).

6. Eikhman, Shemyakin, and Vozhdaeva, *Anilinokraschnaya Prom.*, **4**, 461, 523 (1934); *C.A.*, **29**, 1077, 2520 (1935).

7. Boswell and Dickson, *J. Am. Chem. Soc.*, **40**, 1786 (1918).

8. Willson and Meyer, *Ber.*, **47**, 3160 (1914).

9*a*. Lemberg, *Ber.*, **62B**, 592 (1929). *b*. See also Nollau and Daniels, *J. Am. Chem. Soc.*, **36**, 1885 (1914).

10*a*. Maslennikov, *J. Chem. Ind.* (*Moscow*), **5**, 77 (1928); *C.A.*, **22**, 3884 (1928). *b*. Hale and Britton, U. S. pat., 1,789,071, *C.A.*, **25**, 969 (1931).

11. Engelhardt and Latschinow, *Z. Chem.*, 618 (1869); Barth, *Ann.*, **154**, 358 (1870); Wurtz, *Ann.*, **144**, 122 (1867).

12. Gilman, *Org. Syntheses, Coll. Vol. I*, First Edition, John Wiley & Sons, New York, **1932**, p. 169.

13. Graebe and Kraft, *Ber.*, **39**, **2507** (1906).

14*a*. Beilstein and Kuhlberg, *Ann.*, **155**, 211 (1870). *b*. Sempotowski, *Ber.*, **22**, 2672 (1889). *c*. Spica, *Gazz. chim. ital.*, **8**, 418 (1878); **9**, **442** (1879); **10**, 247 (1880); Paterno and Spica, *ibid.*, **6**, 535 (1876). *d*. Estreicher, *Ber.*, **33**, **442** (1900). *e*. Seńkowski, *Ber.*, **23**, 2418 (1890). *f*. Krafft, *Ber.*, **19**, **2983** (1886).

15. Jacobsen, *Ber.*, **11**, **26** (1878); Wurtz, *Ann.*, **147**, 373 (1878); Armstrong and Wilson, *Chem. News*, **83**, **46** (1901); Bayrac, *Bull. soc. chim.*, [3] **13**, 896 (1895); Müller, *Ber.*, **2**, **130** (1869); Carstanjen, *J. prakt. Chem.*, [2] **15**, **409** (1877); Jacobsen, *Ber.*, **11**, 1060 (1878); Dinesmann, German pat., 125,097, *Chem. Zentr.*, II, 1030 (1901); Baur, *Ber.*, **27**, 1615 (**1894**); Voswinkel, *Ber.*, **22**, **317** (1889); **21**, **2830** (1888); Kelbe, *Ann.*, **210**, **40** (1881); Spica, *Gazz. chim. ital.*, **12**, **552** (1882); Kekulé and Pott, *Ber.*, **2**, 121 (1869).

16*a*. Jacobsen, *Ann.*, **195**, **268** (1879); *Ber.*, **12**, **435** (1879). *b*. *Ber.*, **19**, **2518** (1886). *c*. Reuter, *Ber.*, **11**, **29** (1878). *d*. Biedermann and Ledoux, *Ber.*, **8**, **250** (1875). *e*. Stahl, *Ber.*, **28**, 990 (1890).

17*a*. Töhl, *Ber.*, **21**, 907 (1888). *b*. Jacobsen, *Ber.*, **15**, **1854** (1882). *c*. Jacobsen and Schnapauff, *Ber.*, **18**, **2843** (1885).

18. Jacobsen, *Ber.*, **11**, 18 (1878).

19*a*. Jacobsen, *Ann.*, 206, 200 (1881). *b*. *Ber.*, **20**, 899 (1887).

20. Gibbs and Phillips, *J. Ind. Eng. Chem.*, **12**, 145 (1920).

21. Hixson and McKee, *ibid.*, **12**, 296 (1920); U. S. pat., 1,265,800.

22. Phillips and Gibbs, *J. Ind. Eng. Chem.*, **12**, 733 (1920); Phillips, U. S. pat., 1,432,298, *C.A.*, **17**, 1030 (1923); *J. Am. Chem. Soc.*, **45**, 1492 (1923).

23*a*. Moschner, *Ber.*, **33**, 739 (1900). *b*. Dünkelsbühler, *Ber.*, **33**, 2895 (1900).

24. Schroeter, Svanoe, Einbeck, Geller, and Riebensahm, *Ann.*, 426, 83 (1922); Schroeter, Erzberger, and Passavant, *Ber.*, **71B**, 1040 (1938).

25. Willson and Meyer, *Ber.*, **47**, 3160 (1914).

26. Zollinger and Roehling, U. S. pat., 1,321,271, *C.A.*, **14**, 186 (1920).

27*a*. Badische Anilin- und Sodafabrik, German pat., 132,423, *Chem. Zentr.*, II, 170 (1902). *b*. Boehringer and Söhne, German pats., 286,266, and 284,533, *Frdl.*, **12**, 157, 158.

28. Chem. Fabr. Griesheim-Elektron, German pat., 137,119, *Chem. Zentr.*, I, 112 (1903).

29. Gilliard, Monnett, and Cartier, German pat., 97,099, *ibid.*, II, 521 (1898).

30*a*. Fahlberg, List and Co., German pat., 256,345, *Frdl.*, **11**, 191. *b*. Lambert, German pat., 276,273, *Frdl.*, **12**, 162.

31. Suter and Scrutchfield, *J. Org. Chem.*, **1**, 189 (1936).

32. Goslich, *Ann.*, **180**, 105 (1876).

33. Ges. für Chem. Ind., German pat., 116,339, *Chem. Zentr.*, I, 76 (1901); Ullmann and Herre, *Ann.*, **366**, 114 (1909).

34*a*. Davies and Wood, *J. Chem. Soc.*, 1122 (1928). *b*. Davies and Poole, *ibid.*, 1122 (1927).

35. Oehler, German pat., 74,446, *Frdl.*, 4, 521; German pat., 74,744, *Frdl.*, **3**, 435; German pat., 77,996, *Frdl.*, 4, 522; see also Rudolph, German pat., 104,902, *Chem. Zentr.*, II, 1038 (1899).

36*a*. Haeussermann and Bauer, *Ber.*, **30**, 740 (1897). *b*. Ullmann and Herre, *Ann.*, **366**, 112 (1909). *c*. Ossenbeck and Tietze, German pat., 571,450, *C.A.*, **27**, 2965 (1933); British pat., 396,100, *C.A.*, **28**, 490 (1934).

37. Oppenheim and Voigt, *Ann. Suppl.*, 6, 376 (1833); Limpricht, *Ber.*, **7**, 1352 (1874); Nölting and Stricker, *Ber.*, **20**, 3022 (1887); Blanksma, *Chem. Zentr.*, I, 1051 (1908); Berndsen and Limpricht, *Ann.*, **177**, 102 (1875).

38. Korner and Paterno, *Gazz. chim. ital.*, 2, 448 (1872).

39. Vogt and Henninger, *Ann.*, **165**, 366 (1873); *Bull. soc. chim.*, [2] **21**, 373 (1874).

40. Nevile and Winther, *Ber.*, **15**, 2990 (1882); German pat., 20,713, *Frdl.*, **1**, 564.

41. Grete, *Ann.*, **177**, 233 (1875); Wroblevsky, *Z. Chem.*, 6 (1871); *Ber.*, **7**, 1063 (1874); *Ann.*, **168**, 166 (1873).

42. Gundelach, *Bull. soc. chim.*, [2] **28**, 345 (1877).

43. Degener, *J. prakt. Chem.*, [2] **20**, 308 (1879).

44*a*. Kekulé, *Z. Chem.*, **643** (1867). *b*. Barth and Senhofer, *Ber.*, 9, 973 (1876).

45*a*. Serrant, *Compt. rend.*, **100**, 1465, 1544 (1885). *b*. Herzig, *Ber.*, **18**, 2234 (1880).

46. Sempotowski, *Ber.*, **22**, 2665 (1889).

47. Petersen and Baehr-Predari, *Ann.*, **157**, 136 (1871).

48. Lincke, *J. prakt. Chem.*, [2] **8**, 44 (1873).

49. Amatatsu and Araki, *J. Chem. Soc. Japan*, **52**, 484 (1931); *C.A.*, **26**, 5083 (1932).

50. Fischer, *Monatsh.*, **2**, 337 (1881); Seyda, *Ber.*, **16**, 688, 693 (1883).

51. Ges. für Chem. Ind., German pat., 44,792, *Frdl.*, **2**, 11; Meyer and Sundmacher, *Ber.*, **32**, 2113 (1899).

52. Vorozhtzov and Shemyakin, *Ber.*, **69B**, 148 (1936).

53. Nietzki and Lerch, *Ber.*, **21**, 3221 (1888).

54. Kalle and Co., German pat., 153,123, *Frdl.*, **7**, 94.

55*a*. Barth, *Ann.*, **148**, 34 (1868). *b*. Heintz, *Ann.*, **153**, 330 (1870). *c*. Offerman, *Ann.*, **280**, 1 (1894). *d*. Remsen, *Ann.*, **178**, 281 (1875).

56. Cöllen and Böttinger, *Ber.*, **9**, 1248 (1876).

57. Böttinger, *Ber.*, **8**, 374 (1875).

58. Jacobsen, *Ber.*, **14**, 39, 2356 (1881); Meldrum and Perkin, *J. Chem. Soc.*, **95**, 1894 (1909); **93**, 1419 (1908); Jacobsen, *Ber.*, **11**, 897 (1878); Remsen and Iles, *Am. Chem. J.*, **1**, 48 (1879); *Ber.*, **11**, 890 (1878); Weber, *Ber.*, **25**, 1741 (1892); Flesch, *Ber.*, **6**, 480 (1873); Weinrich, *Ber.*, **20**, 981 (1887); Remsen and Brown, *Am. Chem. J.*, **3**, 218 (1898).

59*a*. Jacobsen and Meyer, *Ber.*, **16**, 190 (1883). *b*. Jacobsen, *Ann.*, **206**, 174 (1881).

60. Tiemann and Ludwig, *Ber.*, **15**, 2051 (1882).

61. Rudnew, *Ann.*, **173**, 10 (1874).

62. Liebermann and Bergami, *Ber.*, **22**, 128 (1889).

63. Remsen, *Ann.*, **179**, 107 (1875).

64. Hirwe and Jambhekar, *J. Indian Chem. Soc.*, **10**, 47 (1933).

65*a*. Remsen, *Z. Chem.*, 295 (1871); Barth, *Ann.*, **159**, 232 (1871). *b*. Kölle, *Ann.*, **164**, 150 (1872); Klepl, *J. prakt. Chem.*, [2] **28**, 196 (1883).

66*a*. Medoks and Dobrovol'skaya, *J. Applied Chem.* (*U.S.S.R.*), **13**, 191 (1940). *b*. Malin, *Ann.*, **152**, 110 (1869).

67. Graebe, *Ber.*, **18**, 1127 (1885); Rée, *Ann.*, **233**, 217 (1886); Jacobsen and Lonnies, *Ber.*, **13**, 1556 (1880); Remsen and Iles, *Am. Chem. J.*, **1**, 122 (1879); Heine, *Ber.*, **13**, 493 (1880).

68. Jacobsen, *Ann.*, **206**, 203 (1881).

69. Graebe and Kraft, *Ber.*, **39**, 2511 (1906).

70. A.-G. für Anilinfabrik, German pat., 25,373, *Frdl.*, **1**, 119.

71. Mulhauser, *Dinglers Polytech. J.*, **263**, 154 (1887); Bindschedler and Busch, *Chem. Ind.* (German), **1**, 371 (1878); Schoop, *Z. für Chem. Ind.*, II, 1 (1887); Barth and Senhofer, *Ber.*, **8**, 1478, 1483 (1875); Degner, *J. prakt. Chem.*, [2] **20**, 318 (1879).

72. Downs, U. S. pat., 1,658,230, *C.A.*, **22**, 1164 (1928).

73. Voluinkin, *J. Applied. Chem.* (*U.S.S.R.*), **9**, 885 (1936); *C.A.*, **30**, 7555 (1936).

74. Garick, *Z. Chem.*, 551 (1869).

75. Brunner, *Sitzungsber. K. Akad. Wiss. Wien.*, **78**, II, 665 (1879).

76. Senhofer, *Ann.*, **164**, 131 (1872); Nölting, *Ber.*, **19**, 136 (1886); Blomstrand and Hokansson, *Ber.*, **5**, 1086 (1872); Klason, *Ber.*, **19**, 2889 (1886).

77. Nevile and Winther, *Ber.*, **15**, 2990 (1882).

78*a*. Wischin, *Ber.*, **23**, 3114 (1890). *b*. Pfannenstill, *J. prakt. Chem.*, [2] **46**, 153 (1892). *c*. Barth and Herzig, *Monatsh.*, **1**, 808 (1880).

79. Barth and Schmidt, *Ber.*, **12**, 1260 (1879).

80*a*. Tedeschi, *Ber.*, **12**, 1271 (1879). *b*. Fischer, *Monatsh.*, **2**, 337 (1881). *c*. Schultz, *Ber.*, **39**, 3345 (1906).

81. Hopfgarten, *Monatsh.*, **14**, 694 (1893).

82. Barth and Senhofer, *Ann.*, **159**, 222 (1871); **164**, 109 (1872).

83*a*. Adams and Graves, *J. Am. Chem. Soc.*, **45**, 2439 (1923). *b*. Lock and Nottes, *Monatsh.*, **68**, 51 (1936).

84. Suter and Weston, *J. Am. Chem. Soc.*, **61**, 234 (1939).

85. Shah and Bhatt, *J. Chem. Soc.*, 1373 (1933).

86*a*. Fahlberg, *Am. Chem. J.*, **2**, 185 (1880). *b*. Weinreich, *Ber.*, **20**, 982 (1887); Jacobsen and Wierss, *Ber.*, **16**, 1960 (1883).

87. Senhofer, *Sitzungsber. K. Akad. Wiss. Wien*, **78**, II, 678 (1879).

88. Suter and Harrington, *J. Am. Chem. Soc.*, **59**, 2575 (1937).

89. Barth and Schreder, *Sitzungsber. K. Akad. Wiss. Wien*, **79**, II, 294 (1879).

90. Tobias, German pat., 81,210, *Frdl.*, **4**, 118.

91. Kretschy, *Ber.*, **11**, 858 (1878).

92. Latschinow, *Ber.*, **6**, 194 (1873).

93. Schultz and Kohlhaus, *Ber.*, **39**, 3343 (1906); Limpricht, *Ann.*, **261**, 327 (1891); Engelhardt and Latschinow, *Z. Chem.*, 260 (1871); Doebner, *Ber.*, **9**, 130 (1876); Schmidt and Schultz, *Ann.*, **207**, 337 (1881).

94. Kruber, *Ber.*, **65B**, 1382 (1932).

95. Bayer and Co., German pat., 90,341, *Frdl.*, **4**, 230.

96. Barth and Schreder, *Ber.*, **11**, 1336 (1878).

97. Heumann and Wiernik, *Ber.*, **20**, 914 (1887); Kade, *Ber.*, **6**, 953 (1873); **7**, 239 (1874).

98. Remsen and Saunders, *Am. Chem. J.*, **17**, 355 (1895).

99. Lapworth, *J. Chem. Soc.*, **73**, 406 (1898).

100. Krannich, *Ber.*, **33**, 3488 (1900).

101. Courtot, *Ann. chim.*, [10] **14**, 5 (1930).

102. Engler, *Ber.*, **11**, 929 (1878).

103. Behr, *Ber.*, **5**, 278 (1872).

104. Eller, *Ann.*, **152**, 275 (1869); Schaeffer, *Ann.*, **152**, 280 (1869); Wallach and Wichelhaus, *Ber.*, **3**, 846 (1870); Maikopar, *Z. Chem.*, 215 (1869); *Frdl.*, **1**, 7; Eikhman and Illyukevich, *Org. Chem. Ind.* (*U.S.S.R.*), **1**, 93 (1936).

105. Fierz-David, "Farbenchemie," Third Edition, Julius Springer, Berlin, 1924, p. 12.

106. Friedländer and Lucht, *Ber.*, **26**, 3034 (1893).

107. Elbs and Christ, *J. prakt. Chem.*, [2] **106**, 17 (1923); Steiger, *Helv. Chim. Acta*, **13**, 173 (1930).

108. Dziewoński and Waszkowski, *Bull. intern. acad. polonaise*, 604 (1929A); *C.A.*, **25**, 1241 (1931); Dziewoński and Kowalczyk, *C.A.*, **30**, 5212 (1936).

109. Dziewoński, Schoenouna, and Waldmann, *Ber.*, **58**, 1213 (1925); Dziewoński and Wulffsohn, *C.A.*, **25**, 1514 (1931).

110. Dziewoński and Dziecielewski, *Bull. intern. acad. polonaise*, 273 (1927A); *C.A.*, **22**, 2164 (1928).

111. Weissgerber and Kruber, *Ber.*, **52**, 351 (1919).

112. Claus, *J. prakt. Chem.*, [2] **39**, 316 (1889); *Ber.*, **22R**, 336 (1889); Emmert, *Ann.*, **241**, 369 (1887); Erdmann, *Ann.*, **247**, 356 (1888); Willstätter and Parnas, *Ber.*, 40, 1406 (1907); Leonhardt & Co., German pat., 55,204, *Frdl.*, **2**, 225; Schultz, *Ber.*, **20**, 3161 (1887); Leman, *Ann. chim.*, 9, 357–446 (1938).

113. Kalle and Co., German pat., 112,176, *Frdl.*, **6**, **221**; *Chem. Zentr.*, II, 700 (1900) Meyer and Hartmann, *Ber.*, **38**, 3950 (1905).

114*a*. Royle and Schedler, *J. Chem. Soc.*, **123**, 1645 (1923). *b*. Meister, Lucius, and Brüning, German pat., 413,836, *Chem. Zentr.*, II, 614 (1925). *c*. Lesser and Gad, *Ber.*, **58**, 2551 (1925). *d*. Battershall, *Ann.*, **168**, 114 (1873). *e*. Stumpf, *Ann.*, **188**, 1 (1877). *f*. Dziewoński, Galitzerówna, and Kocwa, *Bull. intern. acad. polonaise*, 209 (1926A); *Chem. Zentr.*, II, 2818 (1926). *g*. Butler and Royle, *J. Chem. Soc.*, **123**, 1649 (1923).

115. Hosaeus, *Ber.*, **26**, 672 (1893); Schmid, *Ber.*, **26**, 1117 (1893); Ges. für Chem. Ind. Basel, German pat., 69,357, *Frdl.*, **3**, 506.

116*a*. Dziewoński and Stolyhwo, *Ber.*, **57**, 1543 (1924). *b*. Anselm and Zuckmayer, *Ber.*, **32**, 3288 (1899). *c*. Graebe, *Ann.*, **327**, 77 (1903). *d*. Dziewoński and Kocwa, *Bull. intern. acad. polonaise*, 405 (1928); *C.A.*, **23**, 2435 (1929). *e*. Oliveri-Mandala, *Atti accad. Lincei*, **21**, I, 779 (1912); *C.A.*, 6, 2748 (1912).

117. Herz and Schulte, German pat., 531,889, *C.A.*, **26**, 155 (1932).

118. Fierz, *Helv. Chim. Acta*, **3**, 318 (1920).

119. Friedländer, *Ber.*, **28**, 1952 (1895).

120. Sachs, *Ber.*, **39**, 3018 (1906); German pat., 173,522, *Frdl.*, **8**, 172; A.-G. für Anilinfabrik, German pat., 49,448, *Frdl.*, **2**, 280.

121. Cassella and Co., German pat., 69,458, *Frdl.*, **3**, 476; Friedländer and Zinberg, *Ber.*, **29**, 41 (1896).

122. Badische Anilin- und Sodafabrik, German pat., 55,404, *Frdl.*, **2**, 281.

123. Ges. für Chem. Ind. Basel, German pat., 47,816, *Frdl.*, **2**, 278.

124*a*. Badische Anilin- und Sodafabrik, German pat., 112,778, *Frdl.*, **5**, 936. *b*. Cassella and Co., German pat., 75,962, *Frdl.*, **4**, 548.

125. Cleve, *Bull. soc. chim.*, [2] **24**, 513 (1875); Schultz, *Ber.*, **20**, 3161 (1887); Ewer and Pick, German pat., 41,934, *Frdl.*, **1**, 398; Armstrong and Wynne, *Chem. Zentr.*, 380 (1887); Bernthsen and Semper, *Ber.*, **20**, 938 (1887); Erdmann, *Ann.*, **247**, 356 (1888); Bentley, Robinson, and Weizmann, *J. Chem. Soc.*, **91**, 106 (1907); Ewer and Pick, German pat., 45,229, *Frdl.*, **2**, 245; Armstrong and Graham, *J. Chem. Soc.*, **39**, 140 (1881); *Ber.*, **14**, 1286 (1881); Darmstadter and Wichelhaus, *Ann.*, **152**, 306 (1869); Dusart, *Ann.*, **144**, 124 (1867); Ebert and Merz, *Ber.*, **9**, 609 (1876); Weber, *Ber.*, **10**, 1233 (1877); **14**, 2206 (1881); Clausius, *Ber.*, **23**, 519 (1890).

126. Kalle and Co., German pat., 79,028, *Ber.*, **28R**, 364 (1895); Armstrong and Wynne, *Ber.*, **24R**, 718 (1891); see, however, Badische Anilin- und Sodafabrik, German pat., 57,910, *Frdl.*, **2**, 252; 89,061, *Frdl.*, **4**, 598.

127. Ewer and Pick, German pat., 41,934, *Frdl.*, **1**, 398.

128. Ebert and Merz, *Ber.*, 9, 610 (1876); Armstrong and Graham, *J. Chem. Soc.*, **39**, 135 (1881); Cassella and Co., German pat., 45,221, *Frdl.*, **2**, 246.

129. Cassella and Co., German pat., 42,112, *Frdl.*, **1**, 376; German pat., 45,221, *Frdl.*, **2**, 246; Weinberg, *Ber.*, **20**, 2907 (1887); Kogan, *J. Applied Chem.*, (*U.S.S.R.*), **4**, 1060 (1931); *C.A.*, **27**, 78 (1933).

130*a*. Badische Anilin- und Sodafabrik, German pat., 57,525, *Frdl.*, **3**, 495. *b*. Neil, *Ber.*, **39**, 1059 (1906). *c*. Friedländer and Zakrzewski, *Ber.*, **27**, 762 (1894).

131. Friedländer, *Chem.-Ztg.*, **16**, 1799 (1892); Kalle and Co., German pat., 82,422, *Frdl.*, **4**, 551; Höchster Farbw., patent appl., 7,112, *Frdl.*, **4**, 550; Bayer and Co., German pat., 54,116, *Frdl.*, **2**, 315; German pat., 67,829, *Frdl.*, **2**, 447; Badische Anilin- und Sodafabrik, German pat., 57,225, *Frdl.*,

3, 494; Bayer and Co., German pat., 52,873, *Frdl.*, 2, 404; German pat., 56,500, *Frdl.*, 2, 396; German pat., 57,166, *Frdl.*, 3, 660; German pat., 80,667, *Frdl.*, 4, 549.

132. Bayer and Co., German pat., 78,604, *Frdl.*, 4, 604.
133. Binschedler, German pat., 81,938, *Frdl.*, 4, 568; Friedländer and Zinberg, *Ber.*, 29, 38 (1896).
134. Ges. für Chem. Ind. Basel, German pat., 67,000, *Frdl.*, 3, 505; British pat., 149,553, *Chem. Zentr.*, II, 177 (1921); Schmid, *Ber.*, 26, 1114 (1893).
135. Bayer and Co., German pat., 85,241, *Frdl.*, 4, 586; Badische Anilin- und Sodafabrik, German pat., 73,276, *Frdl.*, 3, 488; German pat., 85,088, *Frdl.*, 4, 580; Bayer and Co., patent appl., 7,978, *Frdl.*, 4, 593; Landshoff and Meyer, P.A.C., 3,311, *Mon. Sci.*, 130 (1893); Badische Anilin- und Sodafabrik, German pat., 75,469, *Frdl.*, 3, 690; Bucherer and Wahl, *J. prakt. Chem.*, [2] 103, 129 (1921); *Bull. soc. chim.*, [4] 33, 1481 (1923); Battegay and Wolff, *Chem. Zentr.*, I, 1786 (1924); Kalle and Co., German pat., 233,105, *Frdl.*, 10, 188; Meister, Lucius, and Brüning, German pat., 53,076, *Frdl.*, 2, 284; Täuber and Walder, *Ber.*, 29, 2268 (1896); Friedländer, *Chem.-Ztg.*, 16, 1799 (1892); Bayer and Co., German pat., 75,055, *Frdl.*, 3, 452; Badische Anilin- und Sodafabrik, German pat., 63,074, *Frdl.*, 3, 686; Bayer and Co., German pat., 75,317, *Frdl.*, 3, 450; patent appl., 4,723, *Frdl.*, 3, 454; Meister, Lucius, and Brüning, patent appl., 7,112, *Frdl.*, 4, 550; Cassella and Co., German pat., 75,710, *Frdl.*, 4, 557; German pat., 82,676, *Frdl.*, 4, 572; Dahl and Co., German pat., 68,232, *Frdl.*, 3, 478; Friedländer and Kielbasinski, *Ber.*, 29, 1979 (1896); Cassella and Co.. German pat., 58,352, *Frdl.*, 3, 671; Gubelmann and Tinker, U. S. pat., 1,573,056, *Chem. Zentr.*, I, 3632 (1926).
136. Dahl and Co., German pat., 57,014, *Frdl.*, 2, 274; Bayer and Co., German pat., 75,055, *Frdl.*, 3, 452.
137. Bayer and Co., German pat., 80,668, *Frdl.*, 4, 562.
138. Bayer and Co., German pat., 80,741, *Frdl.*, 4, 564; Bucherer and Zimmermann, *J. prakt. Chem.*, [2] 103, 304 (1922).
139. A.-G. für Anilinfabrik, German pat., 86,448, *Frdl.*, 4, 606; German pat., 86,200, *Frdl.*, 4, 950.
140. Cassella and Co., German pat., 91,000, *Frdl.*, 4, 608.
141. Guerke and Rudolph, German pat., 38,281, *Frdl.*, 1, 385.
142. A.-G. für Anilinfabrik, German pat., 42,261, *Frdl.*, 1, 400; German pat., 63,015, *Frdl.*, 3, 663.
143. Armstrong and Wynne, *Ber.*, 24R, 718 (1891); Friedländer and Rudt, *Ber.*, 29, 1611 (1896); Kalle and Co., German pat., 91,201, *Frdl.*, 4, 148.
144. Friedländer, *Chem.-Ztg.*, 16, 1799 (1892).
145. Dressel and Kothe, *Ber.*, 27, 2144 (1894).
146. Meister, Lucius, and Brüning, German pat., 67,563, *Frdl.*, 3, 460; Rudolph, *Chem.-Ztg.*, 16, 779 (1892); *Ber.*, 25R, 642 (1892).
147. Bayer and Co., German pat., 78,604, *Frdl.*, 4, 604.
148. Bayer and Co., German pat., 40,893, *Frdl.*, 1, 397; German pat., 79,054, *Frdl.*, 4, 589; see also Friedländer and Rudt, *Ber.*, 29, 1613 (1896).
149. Cassella and Co., German pat., 110,618, *Frdl.*, 6, 520; German pat., 112,098, *Chem. Zentr.*, II, 744 (1902).
150. Cassella and Co., German pat., 188,505, *Frdl.*, 8, 1360.
151. Cassella and Co., German pat., 75,432, *Frdl.*, 3, 484.

152. Oehler, German pat., 158,147, *Frdl.*, **8**, 633.

153. Bayer and Co., German pat., 69,722, *Frdl.*, **3**, 468; British pat., 190,114, *Chem. Zentr.*, II, 962 (1923); Dobmaier, U. S. pat., 1,879,132, *C.A.*, **27**, 311 (1933).

154. Bayer and Co., German pat., 80,741, *Frdl.*, **4**, 564; Kalle and Co., German pat., 99,164, *Frdl.*, **5**, 498; *Chem. Zentr.*, II, 1230 (1898).

155. Bayer and Co., German pat., 77,703, *Frdl.*, **4**, 748; German pat., 89,910, *Frdl.*, **4**, 937.

156. Gubelmann and Tinker, U. S. pat., 1,573,056, *Chem. Zentr.*, I, 3632 (1926).

157. Bayer and Co., German pat., 84,597, *Frdl.*, **4**, 563.

158*a*. Liebermann and Hörmann, *Ber.*, **12**, 589 (1879). *b*. Liebermann, *Ann.*, **212**, 49 (1882). *c*. Schmidt, *Ber.*, **37**, 70 (1904). *d*. Dienel, *Ber.*, **38**, 2863 (1905).

159. Ferbero and Conzetti, *Helv. Chim. Acta*, **11**, 1152 (1928).

160. Liebermann, *Ber.*, **11**, 1610 (1878); **12**, 185 (1879); Liebermann and Boeck, *Ber.*, **11**, 1613 (1878); Schüler, *Ber.*, **15**, 1807 (1882).

161. Liebermann, *Ann.*, **212**, 45 (1882).

162*a*. Iljinsky, *Ber.*, **36**, 4198 (1903). *b*. Schmidt, *Ber.*, **37**, 66 (1904).

163. Bayer and Co., German pat., 172,642, *Frdl.*, **8**, 238; Meister, Lucius, and Brüning, German pat., 106,505, *Frdl.*, **5**, 275.

164. Simon, *Ber.*, **14**, 464 (1881).

165. Graebe and Liebermann, *Ann.*, **160**, 143 (1871).

166. See Houben, "Das Anthracen and Anthraquinone," Georg Thieme, Leipzig, 1929, for a discussion of the technical preparation of alizarin.

167. Schunck and Roemer, *Ber.*, **8**, 1628 (1875); **9**, 379 (1876); Roemer and Schwarzer, *Ber.*, **15**, 1040 (1882); Caro, *Ber.*, **9**, 682 (1876); see also Offermann, *Ann.*, **280**, 17 (1894); Bayer and Co., German pats., 50,708, 50,164; *Frdl.*, **2**, 120; **2**, 118.

168. Schmidt, *J. prakt. Chem.*, [2] **43**, 237 (1891); Perger, *ibid.*, [2] **18**, 180 (1878).

169. Wölbling, *Ber.*, **36**, 2941 (1903); Schrobsdorff, *Ber.*, **36**, 2936 (1903); Bayer, German pat., 178,631, *Frdl.*, **8**, 255; German pat., 103,686, *Frdl.*, **5**, 265; German pat., 103,988, *Frdl.*, **5**, 266.

170. Schmidt, *Ber.*, **37**, 66 (1904); Wedekind and Co., German pat., 170,329, *Frdl.*, **8**, 233; German pat., 195,874, *Frdl.*, **9**, 683; German pat., 202,398, *Frdl.*, **9**, 671; Meister, Lucius, and Brüning, German pat., 158,413, *Frdl.*, **8**, 263; German pat., 106,505, *Frdl.*, **5**, 275; Bayer, German pat., 197,607, *Frdl.*, **9**, 680; German pat., 170,108 (not in *Frdl.*); German pat., 178,631, *Frdl.*, **8**, 255; see ref. 145, pp. 348–354, 400, 402, 422, 439; Perkin and Cope, *J. Chem. Soc.*, **65**, 844 (1894).

171. Werner and co-workers, *Ann.*, **321**, 248 (1902).

172. Fieser, *J. Am. Chem. Soc.*, **51**, 2460 (1929).

173. Fieser, *ibid.*, **51**, 2478 (1929).

174. Fieser and Young, *ibid.*, **53**, 4120 (1931); Komppa and Wahlforss, *ibid.*, **52**, 5009 (1930).

175. Werner, *Ann.*, **321**, 341 (1902).

176. Dziewoński and Stalyhwo, *Ber.*, **57B**, 1531 (1924).

177. Courtot and Geoffroy, *Compt. rend.*, **178**, 2259 (1924); **180**, 1665 (1925); Schmidt, Retzlaff, and Haid, *Ann.*, **390**, 217 (1912).

178. Bedall and Fischer, *Ber.*, **14**, 442, 1366 (1881); see also Vorozhtzov and Kogan, *Ber.*, **65B**, 142 (1932).

179. I. G. Farbenind. A.-G., British pat., 417,794, *C.A.*, **29**, 1438 (1935).

180. I. G. Farbenind. A.-G., German pat., 553,714, *C.A.*, **26**, 5577 (1932).
181. Lehmstedt and Wirth, *Ber.*, **61B**, 2044 (1928).
182*a*. Jackson and Wing, *Ber.*, **19**, 902 (1886); *Am. Chem. J.*, **9**, 76 (1887). *b*. Sachs, *Ber.*, **39**, 3014 (1906).
183. Sachs, German pat., 173,522, *Chem. Zentr.*, II, 931 (1906).
184. Fierz, *Helv. Chim. Acta*, **3**, 318 (1920).
185. Willgerodt and Mohr, *J. prakt. Chem.*, [2] **34**, 116 (1886).
186. Kalle and Co., German pat., 94,075, *Frdl.*, **4**, 601.
187. Friedländer and Taussig, *Ber.*, **30**, 1462 (1897).
188. Kalle and Co., German pat., 89,061, *Frdl.*, **4**, 599.
189. Kalle and Co., German pats., 90,905 and 90,906, *Frdl.*, **4**, 599, 600.
190. Schmidt, *Ber.*, **37**, 70 (1904); Bayer and Co., German pat., 149,801, *Frdl.*, **7**, 194; German pat., 175,024, *Frdl.*, **8**, 284; *Chem. Zentr.*, II, 1465 (1906).
191*a*. Bourcart, *Ber.*, **12**, 1418 (1879). *b*. Perger, *Ber.*, **12**, 1567 (1879).
192. Bayer and Co., German pat., 135,634, *Chem. Zentr.*, II, 1232 (1902).
193. Bourcart, *Bull. soc. chim.*, [2] **33**, 264 (1880); Kaufler, *Ann.*, **351**, 158 (1907).
194. Gubelmann, Weiland, and Stallmann, *J. Am. Chem. Soc.*, **53**, 1036 (1931).
195. Lauer, *J. prakt. Chem.*, **135**, 204 (1932).
196. Il'inskiĭ and Nikolaeva, *Anilinokrasochnaya Prom.*, **4**, 564 (1934); *C.A.*, **29**, 2530 (1935).
197. Badische Anilin- und Sodafabrik, German pat., 256,515, *Chem. Zentr.*, I, 866 (1913).
198. Maki, *J. Soc. Chem. Ind. Japan*, **32**, Suppl. binding, 344 (1929).
199. Meyer, *Ber.*, **3**, 113 (1870); *Ann.*, **156**, 273 (1870).
200. Remsen, *Ber.*, **8**, 1412 (1875); Jacobsen, *Ber.*, **11**, 18, 23 (1878); Reuter, *Ber.*, **11**, 29 (1878).
201. Whitmore and Fox, *J. Am. Chem. Soc.*, **51**, 3364 (1929); Meyer, *Ber.*, **3**, 364 (1870).
202. Ader and Oppenheim, *Ber.*, **3**, 114 (1870); Remsen, *Ann.*, **178**, 290 (1875).
203. Remsen and Iles, *Am. Chem. J.*, **1**, 48 (1879).
204. Senhofer, *Ann.*, **164**, 134 (1872).
205. Ascher, *Ann.*, **161**, 2 (1872).
206. Böttinger, *Ber.*, **7**, 1782 (1874); *Ann.*, **191**, 28 (1878).
207. Cöllen and Böttinger, *Ber.*, **9**, 1248 (1876).
208. Barth and Senhofer, *Ann.*, **159**, 228 (1871).
209. Heine, *Ber.*, **13**, 493 (1880).
210. Merz, *Z. Chem.*, **4**, 33, 396 (1868).
211. Witt, *Ber.*, **6**, 448 (1873).
212. Meyer and Stüber, *Ann.*, **165**, 166 (1873).
213. Limpricht, *Ann.*, **180**, 92 (1875).
214*a*. Nölting, *Ber.*, **8**, 1113 (1875). *b*. Irelan, *Z. Chem.*, 164 (1869). *c*. Barth and Senhofer, *Ann.*, **174**, 242 (1874).
215. Fittig and Ramsay, *Ann.*, **168**, 246 (1873).
216. Paterno and Spica, *Gazz. chim. ital.*, **5**, 26 (1875); *Ber.*, **8**, 441 (1875).
217. Paterno and Fileti, *ibid.*, **5**, 30 (1875); *Ber.*, **8**, 442 (1875).
218. Boessneck, *Ber.*, **16**, 639 (1883).
219. Whitmore and Fox, *J. Am. Chem. Soc.*, **51**, 3364 (1929).
220. Merz and Mühlhäuser, *Ber.*, **3**, 710 (1870).
221. Vieth, *Ann.*, **180**, 305 (1875); *Ber.*, **8**, 1278 (1873); Ekstrand, *J. prakt. Chem.*, [2] **38**, 139 (1888).

222. Doebner, *Ann.*, **172**, 111 (1874).

223. Rassow, *Ann.*, **282**, 142 (1894).

224. Fieser, *J. Am. Chem. Soc.*, **54**, 4110 (1932).

225. Werner and Ney, *Ann.*, **321**, 328 (1902).

226*a*. Japp and Schultz, *Ber.*, **10**, 1661 (1877); Schultz, *Ann.*, **196**, 13 (1879). *b*. Werner and Kunz, *Ann.*, **321**, 323 (1902).

227. Japp, *J. Chem. Soc.*, **37**, 83 (1880).

228. Oliveri-Mandalà, *Atti accad. Lincei*, [5] **21**, I, 779 (1912).

229*a*. Barth and Senhofer, *Ann.*, **174**, 236 (1874); *Ber.*, **8**, 1481 (1875). *b*. Korner and Monselise, *Gazz. chim. ital.*, **6**, 139 (1876). *c*. Meyer and Michler, *Ber.*, **8**, 673 (1875).

230. Korner and Monselise, *Ber.*, **9**, 584 (1876); Garrick and Fittig, *Ann.*, **174**, 124 (1874).

231. Ebert and Merz, *Ber.*, **9**, 604 (1876).

232. Doebner, *Ann.*, **172**, 116 (1874).

233. Goldschmidt and Wegscheider, *Monatsh.*, **4**, 242 (1883).

234. Jackson and Wing, *Am. Chem. J.*, **9**, 329 (1887).

235. Stadler, *Ber.*, **17**, 2080 (1884).

236. Schwalbe, *Ber.*, **39**, 3104 (1906).

237. Willgerodt and Mohr, *J. prakt. Chem.*, [2] **34**, 116 (1886).

238. Bayer and Co., German pat., 212,857, *Frdl.*, **9**, 704; *Chem. Zentr.*, II, 774 (1909).

239. Decker and Würsch, *Ann.*, **348**, 239 (1906).

240*a*. Reid, Mackall, and Miller, *J. Am. Chem. Soc.*, **43**, 2104 (1921). *b*. Hoffman and Reid, *ibid.*, **45**, 1831 (1923).

241. Bayer and Co., German pat., 224,589, *Frdl.*, **10**, 597.

242. Armstrong, *Ber.*, **7**, 407 (1874).

243. Schmidt, *Ber.*, **37**, 70 (1904); Bayer and Co., German pat., 156,762, *Frdl.*, **8**, 240; *Chem. Zentr.*, I, 313 (1905).

244. Bayer and Co., German pat., 166,748, *Frdl.*, **8**, 241; *Chem. Zentr.*, I, 517 (1906).

245. Bayer and Co., German pat., 158,531, *Frdl.*, **8**, 242; *Chem. Zentr.*, I, 1517 (1905).

246. Laube, *Ber.*, **39**, 2245 (1906).

247. Decker and Laube, *Ann.*, **348**, 233 (1906).

248. I. G. Farbenind. A.-G., British pat., 359,397, *C.A.*, **27**, 310 (1933).

249. Bayer and Co., German pat., 84,505, *Frdl.*, **4**, 300; German pat., 162,035, *Frdl.*, **8**, 259; *Chem. Zentr.*, II, 864 (1905).

CHAPTER V

DERIVATIVES OF AROMATIC SULFONIC ACIDS. 1 SULFONYL HALIDES, ESTERS, AND ANHYDRIDES

CONTENTS

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Derivatives of sulfonic acids are of two types: (1) salts of inorganic or organic bases and (2) sulfonyl halides and compounds obtained from them. Substances belonging in the first category have been described in the preceding chapter. Of the sulfonyl halides, the chlorides have been prepared for most sulfonic acids and the fluorides have received considerable attention in recent years while the bromides and iodides have been studied but little. From the sulfonyl chlorides many amides and esters have been made; hydrazides, azides, and anhydrides are less well known. The aminosulfonamides and their derivatives have been intensively investigated in recent years because of their value as chemotherapeutic agents. The literature on saccharin and its derivatives, N-haloamides of the Chloramine T type, and alkyl sulfonates is also voluminous. The sulfonephthaleins, obtained from *o*-sulfobenzoic anhydride, are important as indicators and in medicine.

Much of the information available concerning sulfonyl halides and amides is most conveniently presented in tabular form because the methods for their preparation are standardized and the knowledge of their properties does not extend, for most compounds, beyond their melting points.

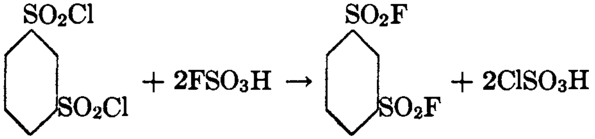
SULFONYL FLUORIDES

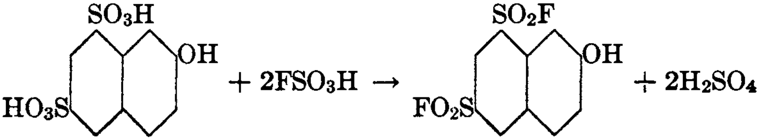
Although compounds containing the sulfonyl fluoride group have been known for only a short time much information is at hand concerning their preparation and properties.

Two general methods are available for synthesizing sulfonyl fluorides. As has already been noted in the section on sulfonations fluorosulfonic acid reacts with many aromatic compounds as shown in the equation,

$$C_6H_6 + 2FSO_3H \rightarrow C_6H_5SO_2F + H_2SO_4 + HF$$

Since fluorosulfonic acid is not a vigorous sulfonating agent it is frequently convenient to employ a sulfonic acid or sulfonyl chloride as the starting material.[1,2,3] Since fluorosulfonic acid has become readily available sulfonyl fluorides are now accessible substances.





A second method of preparation which makes unnecessary the handling of the corrosive fluorosulfonic acid consists in refluxing a sulfonyl chloride with an aqueous solution of a metal fluoride, the highly soluble potassium fluoride giving best results.[4a] Reaction does not occur readily in a non-polar solvent such as benzene. The yields of monosulfonyl fluorides range from 60–80% while for di and trisulfonyl fluorides they are less. This method has been found to be unsuccessful only when an *ortho* substituent interferes by inducing a side reaction. Thus *o*-chlorosulfonylbenzoyl chloride[4b] undergoes complete hydrolysis in aqueous potassium fluoride, apparently by the following steps.

$$C_6H_5SO_2Cl + KF \rightarrow C_6H_5SO_2F + KCl$$

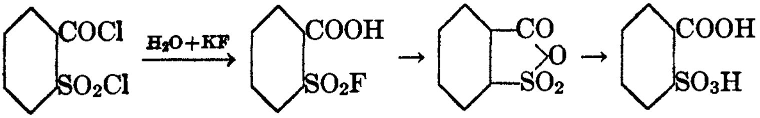


TABLE I

A. *Monosulfonyl Fluorides*

Sulfonyl Fluoride	Reagent Used in Preparation	B.P., °C.	M.P., °C. (or n_D^{20})
$C_6H_5SO_2F$	KF or FSO_3H	207, 203–204	(1.4922)
p-$ClC_6H_4SO_2F$	KF		47–48
p-$HOC_6H_4SO_2F$	FSO_3H		77
o-$O_2NC_6H_4SO_2F$	KF		60
p-$CH_3OC_6H_4SO_2F$	FSO_3H	175/60 mm.	13
p-$C_2H_5OC_6H_4SO_2F$	FSO_3H	170–175/25 mm.	38
4,3-$HO(O_2N)C_6H_3SO_2F$	FSO_3H		66–67
4,3-$HO(H_2N)C_6H_3SO_2F$	FSO_3H		131.5
4,3-$HO(Cl)C_6H_3SO_2F$	FSO_3H		83–84
o-$CH_3C_6H_4SO_2F$	KF or FSO_3H	223–225	(1.5007)
p-$CH_3C_6H_4SO_2F$	KF or FSO_3H	112.5/16 mm.	43–44
p-$C_2H_5C_6H_4SO_2F$	FSO_3H	238–239	
2,3-$CH_3(Cl)C_6H_3SO_2F$	KF		44–45
5,2,4-$Cl(O_2N)(CH_3)C_6H_2SO_2F$	KF		84–85
2,5-$HO(CH_3)C_6H_3SO_2F$	FSO_3H	135–136/20 mm.	58–59
4,3-$HO(CH_3)C_6H_3SO_2F$	FSO_3H	168–170/11 mm.	56–57
4,2-$HO(CH_3)C_6H_3SO_2F$	FSO_3H	169–170/11 mm.	49–50.5
2,3,5-$HO(Br)(CH_3)C_6H_2SO_2F$	FSO_3H		75
1,4-$CH_3(OH)C_6H_2(SO_3K)SO_2F$-3,5	FSO_3H		120–121
o-$NCC_6H_4SO_2F$	KF		88–89
m-$HOOCC_6H_4SO_2F$	FSO_3H		154–155
p-$HOOCC_6H_4SO_2F$	KF		271
3,4-$HOOC(HO)C_6H_3SO_2F$	FSO_3H		183
2,4-$(CH_3)_2C_6H_3SO_2F$	KF or FSO_3H	246, 239–240	(1.5086)
2,5-$(CH_3)_2C_6H_3SO_2F$	FSO_3H	124–125/21 mm.	24.5
2,3,5-$HO(CH_3)_2C_6H_2SO_2F$	FSO_3H	71–73/?	
4,2,6-$HO(CH_3)_2C_6H_2SO_2F$	FSO_3H		107–108
2,4,6-$(CH_3)_3C_6H_2SO_2F$	FSO_3H	125/12 mm.	73–73.5
2,4,5-$(CH_3)_3C_6H_2SO_2F$	FSO_3H	123–126/12 mm.	
2,6,4-$(CH_3)_2[(CH_3)_3C]C_6H_2SO_2F$	FSO_3H		115–116
1-$C_{10}H_{11}SO_2F$(tetralin)	FSO_3H		75–77
α-$C_{10}H_7SO_2F$	FSO_3H		56
β-$C_{10}H_7SO_2F$	KF or FSO_3H		86–88

B. *Disulfonyl Fluorides*

Sulfonyl Fluoride	Reagent Used in Preparation	B.P., °C.	M.P., °C. (or n_D^{20})
1,3-$C_6H_4(SO_2F)_2$	KF or FSO_3H		38–39
4-$ClC_6H_3(SO_2F)_2$-1,3	KF		88–89
4-$HOC_6H_3(SO_2F)_2$-1,3	FSO_3H		120–121
6,4-$CH_3(HO)C_6H_2(SO_2F)_2$-1,3	FSO_3H		125–126.5
4,6-$Cl_2C_6H_2(SO_2F)_2$-1,3	KF		141–143
4,6-$(CH_3O)_2C_6H_2(SO_2F)_2$-1,3	KF		209–211
2,4,6-$Cl_3C_6H(SO_2F)_2$-1,3	KF		109–110
4-$CH_3C_6H_3(SO_2F)_2$-1,3	FSO_3H		87–88
4,6-$(CH_3)_2C_6H_2(SO_2F)_2$-1,3	KF or FSO_3H		116–118

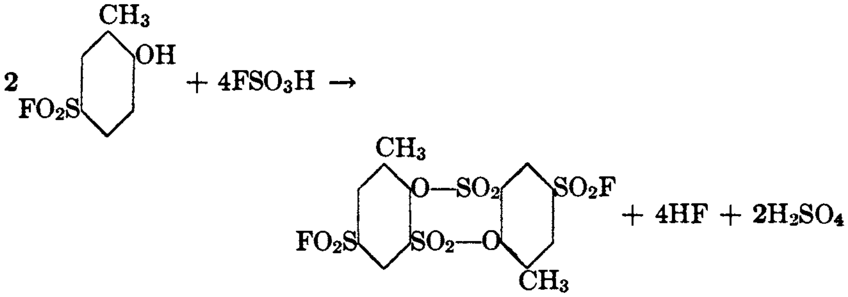
TABLE I (*Continued*)

SULFONYL FLUORIDE	REAGENT USED IN PREPARATION	B.P., °C.	M.P., °C. (OR n_D^{20})
	B. Disulfonyl Fluorides (Continued)		
$1,5\text{-}C_{10}H_6(SO_2F)_2$	FSO_3H	....	203
$2\text{-}HOC_{10}H_5(SO_2F)_2\text{-}3,6$	FSO_3H	....	108–109.5
$2\text{-}HOC_{10}H_5(SO_2F)_2\text{-}6,8$	FSO_3H	....	175–176
	C. Trisulfonyl Fluorides		
$1,3,5\text{-}C_6H_3(SO_2F)_3$	KF	....	166–167
$6\text{-}ClC_6H_2(SO_2F)_3\text{-}1,2,5$	KF	....	179–181
$2\text{-}HOC_{10}H_4(SO_2F)_3\text{-}3,6,8$	FSO_3H	....	153–159

In benzene with zinc fluoride a little of the anhydride was obtained. *p*-Chlorosulfonylbenzoyl chloride yields *p*-fluorosulfonylbenzoic acid which is in accord with the mechanism postulated to explain the behavior of the *ortho* compound.

In Table I are listed the sulfonyl fluorides obtained by the two methods already described. Other sulfonyl fluorides have been prepared by substitution and oxidation reactions of those in the table. Most of these are mentioned in the discussion of reactions of sulfonyl fluorides and the others are described in the references given in this section.

Under conditions which might be expected to lead to the formation of disulfonyl fluorides[2] some phenolsulfonyl fluorides are converted into sulfonylides.



p-Cresolsulfonyl fluoride and 2,4-dimcthylphenol-6-sulfonyl fluoride behave in the same manner.

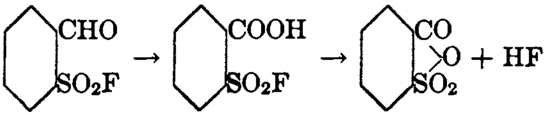
Sulfonyl fluorides are much less reactive than the corresponding chlorides and are therefore of particular interest in reactions where it is desirable that the sulfonyl halide group remain unaffected. They also show an unexpected selectivity in activity toward various groups. Thus benzenesulfonyl fluoride reacts with concentrated aqueous ammonia in a few minutes[1] and with liquid ammonia when allowed to stand with it overnight, to give the sulfonamide, but refluxing with aniline for several hours causes no change. Reaction with phenylhydrazine proceeds slowly, a low yield of the sulfonhydrazide being isolated after a day's standing.

$$C_6H_5SO_2F + 2C_6H_5NHNH_2 \rightarrow C_6H_5SO_2NHNHC_6H_5 + C_6H_5NHNH_3F$$

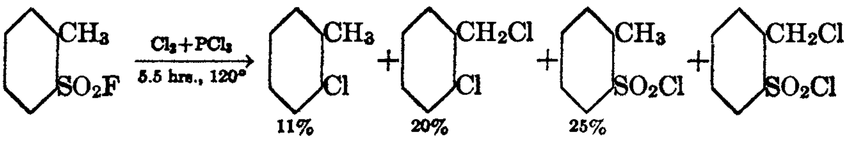
In contrast with the behavior of benzenesulfonyl fluoride, *p*-phenolsulfonyl fluoride is converted into the anilide by warming with aniline at 100° for 1 hour. Standing in alcohol solution for several days gives none of the ethyl ester but reaction occurs readily below 15° when alkali is added, a high yield of ethyl benzenesulfonate resulting.

$$C_6H_5SO_2F + NaOH + C_2H_5OH \rightarrow C_6H_5SO_3C_2H_5 + NaF + H_2O$$

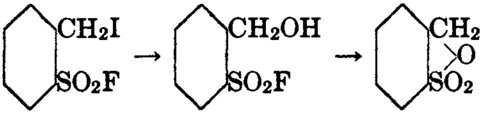
Reduction of the sulfonyl fluoride group is effected with difficulty, benzenesulfonyl fluoride giving less than 20% of thiophenol when treated with excess zinc and acid. This is further shown by the reduction of *m*-nitrobenzenesulfonyl fluoride (obtained in 96% yield by nitration [5]) with tin and hydrochloric acid to the amine without reducing the sulfonyl fluoride group. Other nitro compounds have been treated similarly.[1] The toluenesulfonyl fluorides show no hydrolysis when boiled with water for 8 hours, reaction occurring slowly in 25% sulfuric acid, the *ortho* compound reacting less readily than the *para* isomer. This slow reaction with acid or neutral hydrolyzing agents makes possible oxidation of *p*-toluenesulfonyl fluoride to the benzoic acid with chromium trioxide in acetic acid solution. However, the *ortho* isomer is either hydrolyzed or recovered unchanged.[4b] With chromyl chloride it is possible to obtain benzaldehyde-*o*-sulfonyl fluoride which oxidizes readily in the air to give the unstable acid.



Chlorination of *o*-toluenesulfonyl fluoride for 11 hours at 180–200° leads to substitution in the methyl group while at a lower temperature and a longer reaction time the sulfonyl fluoride group is replaced.[4b] In the presence of a trace of phosphorus trichloride the products are as follows.



One unexpected product from the chlorination at 140–175° for 57 hours was *o*-fluorobenzal chloride. ω-Iodotoluene-*o*-sulfonyl fluoride obtained from the chloride and sodium iodide in acetone is a strong lachrymator. ω-Hydroxytoluene-*p*-sulfonyl fluoride was readily prepared from the iodide and silver oxide, but for the *ortho* compound the sultone is produced as an impurity.

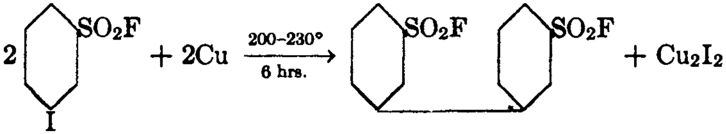


The fluorine of a sulfonyl fluoride is replaced by the chlorine[2] of chlorosulfonic acid upon long standing with this reagent. Aluminum chloride in carbon disulfide solution also effects this change.[1]

$$C_6H_5SO_2F + AlCl_3 \rightarrow C_6H_5SO_2Cl + AlCl_2F$$

Benzenesulfonyl fluoride and *p*-phenolsulfonyl fluoride react with benzene in the presence of aluminum chloride to give the sulfones.

The sulfonyl fluoride group is not attacked by copper, hence it is possible to convert *m*-iodobenzenesulfonyl fluoride into the biphenyldisulfonyl fluoride.[2] 2-Iodotoluene-4-sulfonyl flouride and 2-iodoanisole-4-sulfonyl fluoride react in the same manner. 3-Aminosulfonyl fluoride has been converted by the diazo reaction into the arsonic acid from which a variety of derivatives were prepared.[2]



A number of interesting observations have been made on the reactions of sulfonyl fluorides with Grignard reagents. Benzenesulfonyl fluoride reacts with methyl or ethylmagnesium iodide to give a β-disulfone.[6] Similar results have been reported for the action of *p*-toluenesulfonyl fluoride, *p*-ethylbenzenesulfonyl fluoride, and 2,4-dimethylbenzenesulfonyl fluoride[8] with methylmagnesium iodide. The reactions are not in accord with the equation as written since an excess of the Grignard reagent was employed. The disulfone does not result

$$2C_6H_5SO_2F + C_2H_5MgI \rightarrow (C_6H_5SO_2)_2CHCH_3 + MgBrF + HF$$

$$2p\text{-}CH_3C_6H_4SO_2F + CH_3MgI \rightarrow (p\text{-}CH_3C_6H_4SO_2)_2CH_2 + [MgIF + HF]$$

from the action of the aryl alkyl sulfone with the Grignard reagent, however, as phenyl methyl sulfone and methylmagnesium iodide do not react at room temperature, while in boiling xylene reduction to thiophenol occurs. If benzenesulfonyl fluoride and then chloromethyl phenyl sulfone are added to ethylmagnesium iodide the product is apparently bis-(phenylsulfonyl)-chloromethane since by reduction removal of the chlorine occurs. Isopropylmagnesium bromide reacts quite differently than the primary alkyl Grignard reagents, *p*-toluenesulfonyl fluoride giving an α-disulfone.[6]

$$2p\text{-}CH_3C_6H_4SO_2F + (CH_3)_2CHMgBr \rightarrow (p\text{-}CH_3C_6H_4SO_2)_2 + [MgBrF + C_3H_7F]$$

Interestingly enough the Grignard reagent from 1,5-dichloropentane with 2,4-dimethylbenzenesulfonyl fluoride[3] gives a di rather than a tetrasulfone. Phenylmagnesium bromide behaves in the same way

$$ClMg(CH_2)_5MgCl + 2(CH_3)_2C_6H_3SO_2F \rightarrow [(CH_3)_2C_6H_3SO_2CH_2CH_2]_2CH_2 + 2MgClF$$

with either 2,4-dimethylbenzenesulfonyl fluoride or 1,3-dimethylbenzene-4,6-disulfonyl fluoride.[3]

$$(CH_3)_2C_6H_2(SO_2F)_2 + 2C_6H_5MgBr \rightarrow (CH_3)_2C_6H_2(SO_2C_6H_5)_2 + 2MgBrF$$

When benzenesulfonyl fluoride is heated at 240° for 16 hours with sodium benzoate a mixture of benzoic anhydride and benzoyl fluoride is produced.[2]

SULFONYL CHLORIDES

Methods of Preparation

The direct conversion of a variety of aromatic compounds into sulfonyl chlorides by chlorosulfonic acid has already been noted in the section on sulfonation. This reagent is particularly useful in the synthesis of phenol[7] and amine[8] sulfonyl chlorides where the reaction of sulfonic acid salts with phosphorus pentachloride cannot be employed. Phenol and its simple derivatives all yield di or trisulfonyl chlorides with chlorosulfonic acid but if the phenol is first converted into its carbethoxy ester a monosulfonyl chloride can be obtained.[9] It is not always possible to prepare monosulfonyl chlorides by the action of chlorosulfonic acid on alkyl ethers of phenols,[9, 10] 2,4-disulfonyl chlorides resulting. However, a substituted phenyl ether such as *p*-bromophenyl phenyl ether does give a monosulfonyl chloride in fair yields,[11a] and alkyl aryl ethers [11b] react satisfactorily in chloroform solution in most instances.[12]

With piperonyl nitrile (3,4-methylenedioxybenzonitrile [13]) condensation to the anthraquinonediimide occurs rather than formation of a sulfonyl chloride. Acetanilide [12a] and substituted anilides [14] are readily converted into monosulfonyl chlorides.[15]

Chlorosulfonic acid may be used to convert sulfonic acids or their salts into sulfonyl chlorides [16] making this reagent of value in obtaining sulfonyl chlorides which do not result by direct sulfonation. This reaction has been employed infrequently, however.

$$C_6H_5SO_3Na + ClSO_3H \rightarrow C_6H_5SO_2Cl + NaHSO_4$$

Since chlorosulfonic acid has been in general use for the preparation of sulfonyl chlorides only comparatively recently, most of these compounds described in the literature have been made by other methods, by far the majority having been obtained by the action of phosphorus pentachloride upon an alkali sulfonate.

$$ArSO_3Na + PCl_5 \rightarrow ArSO_2Cl + POCl_3 + NaCl$$

$$2ArSO_3Na + POCl_3 \rightarrow 2ArSO_2Cl + NaPO_3 + NaCl$$

The only limitation upon this method is the presence in the molecule of groups such as hydroxyl which react with phosphorus chlorides. Thus potassium *p*-phenolsulfonate with phosphorus pentachloride [17] gives a phosphate. With a second molecule of phosphorus pentachloride [18,19] at 180° the chlorosulfonyl group is replaced while at 250° *p*-dichlorobenzene is formed quantitatively.[19] By using the theoretical amount of water the chlorine of the phosphate group is readily removed but hydrolysis to *p*-phenolsulfonyl chloride has not been accomplished. The reaction of sodium *o*-phenolsulfonate with phosphorus pentachloride is precisely analogous to that of the *para* compound.[20] However, if sodium *m*-phenolsulfonate is warmed with this

$$p\text{-}HOC_6H_4SO_3K + PCl_5 \rightarrow Cl_2OPOC_6H_4SO_2Cl + HCl + KCl$$

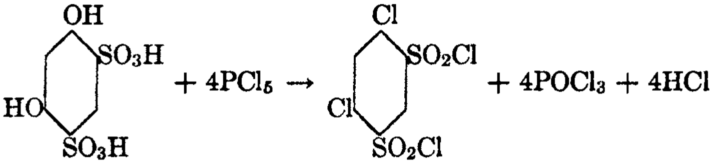
$$Cl_2OPOC_6H_4SO_2Cl + PCl_5 \rightarrow Cl_2OPOC_6H_4Cl + SOCl_2 + POCl_3$$

$$Cl_2OPOC_6H_4Cl + PCl_5 \rightarrow p\text{-}C_6H_4Cl_2 + 2POCl_3$$

$$Cl_2OPOC_6H_4SO_2Cl + H_2O \rightarrow O_2POC_6H_4SO_2Cl + 2HCl$$

reagent and the product washed with water,[21] *m*-phenolsulfonyl chloride is obtained. It seems probable that the phosphate first formed hydrolyzes easily rather than that the hydroxyl group is not esterified.

Heating sodium phenol-2,4-disulfonate with phosphorus pentachloride to 140–150° gives chlorobenzene-2,4-disulfonyl chloride,[22] the hydroxyl being more easily replaceable than the sulfonyl chloride group. This is the reverse of the behavior of the monosulfonates as was noted earlier. Sodium phenol-2,4,6-trisulfonate[22] and resorcinol-4,6-disulfonic acid behave in the same manner.[23] 3,5-Dibromo-4-hydroxybenzenesulfonic acid gives a phosphate[17,19] just as does the unbrominated compound but 4-methyl-6-nitrophenol-2-sulfonic acid and 4-methylphenol-2,6-disulfonic acid[24a] are converted to the sulfonyl chlorides without affecting the hydroxy group. Potassium 2-methyl-6-bromophenol-4-sulfonate[24b] is converted to the hydroxysulfonyl chloride by heating with phosphorus oxychloride to 150° whereas the isomeric 4-methyl-6-bromophenol-2-sulfonate[18b] gives both the hydroxysulfonyl chloride and the dichlorophosphate of this.



Treating α- and β-naphtholsulfonic acids with phosphorus oxychloride yields complex condensation products.[25]

When the hydroxyl group of phenolic sulfonic acids has been protected by reaction with acetic anhydride[19,20] or ethyl chloroformate[26] reaction with phosphorus pentachloride proceeds normally, the ester group not being affected.

It has been reported that aminoanthraquinonesulfonic acids or their salts react with phosphorus pentachloride in the presence of phosphorus oxychloride to give the corresponding sulfonyl chlorides without affecting the amino group.[27]

Of the less used methods for obtaining aromatic sulfonyl chlorides, the only one with practical value is the action of chlorine in water solution upon thiophenols and their derivatives, disulfides, or sulfinic

$$\mathrm{ArSO_2H + Cl_2 \rightarrow ArSO_2Cl + HCl}$$

$$\mathrm{(ArS)_2 + 4H_2O + 5Cl_2 \rightarrow 2ArSO_2Cl + 8HCl}$$

$$\mathrm{2ArSH + 6Cl_2 + 4H_2O \rightarrow 2ArSO_2Cl + 10HCl}$$

acids. Thus benzenesulfinic acid,[28a] thiophenol,[28b] diphenyl disulfide,[28c] phenyl thiocyanate,[28d] sodium 3-nitrobenzenesulfinic acid,[29] *p*-nitrophenylsulfur chloride,[30a] 2,4-dinitrophenylthiuronium chloride,[30b] sodium *o*-toluenesulfinate,[31] *p*-toluenesulfinic acid,[32] *p*-thiocresol,[33] di-(4-methyl-3-bromophenyl) disulfide,[33] di-(4-methyl-2-bromophenyl) disulfide,[33] di-(2-nitro-4-methylphenyl) disulfide,[34] dithiohydroquinone,[35] dithioresorcinol,[36] potassium *m*-benzenedisulfinate,[37] potassium toluene-2,4-disulfinate,[38] biphenyl-4,4′-dithiol,[39] trithiophloroglucinol,[40] toluene-2,4,6-trithiol,[40] 2-(2-methoxyphenylsulfonyl)-benzenesulfinic acid [41a] and the ethoxy compound,[41a] and 4-nitronaphthalene-1-sulfinic acid [41b] have been converted into sulfonyl chlorides by the action of chlorine in water or acetic acid solution (or suspension). Chlorine in chloroform solution converts nitrobenzenesulfonhydrazides into the sulfonyl chlorides.[41c] It seems probable that for the reactions in acetic acid solution the oxygen is furnished by a small amount of water present rather than by the acetic acid.

Chlorine reacts with sulfones and sulfides by cleavage of a carbon-sulfur bond and formation of a sulfonyl chloride. Thus phenyl sulfone [42] reacts at 120–130° to give benzenesulfonyl chloride and chlorobenzene.

$$(C_6H_5)_2SO_2 + Cl_2 \rightarrow C_6H_5SO_2Cl + C_6H_5Cl$$

Phosphorus pentachloride may serve as the source of the chlorine.[43] Diphenyl ethylene disulfone has been observed [44] to react with chlorine to give benzenesulfonyl chloride as one product.

$$(C_6H_5)_2SO_2 + PCl_5 \rightarrow C_6H_5Cl + C_6H_5SO_2Cl + PCl_3$$

Chlorination of *p*-iodophenyl methyl or ethyl sulfide in the presence of moisture from the air gives as the final product *p*-iodobenzenesulfonyl chloride.[45] As the first stage the hydrogens of the alkyl group are replaced. Bromine does not react in this manner. The iodine addition product of 2,5-dibromo-1,4-phenylene dimethyl disulfide also is converted to the disulfonyl chloride by chlorine in acetic acid.[35]

$$C_6H_5SCH_3 + 3Cl_2 \rightarrow C_6H_5SCCl_3 + 3HCl$$

Chlorine brings about decomposition of potassium benzenethiosulfonate in water solution to give the acid chloride.[46]

$$C_6H_5SO_2SK + Cl_2 \rightarrow C_6H_5SO_2Cl + S + KCl$$

Phosphorus oxychloride [47] and aqueous ferric chloride [48] achieve the same end.

$$C_6H_5SO_2SK + FeCl_3 \rightarrow C_6H_5SO_2Cl + S + FeCl_2$$

N,N-Dichlorobenzenesulfonamide[49] pyrolyzes at 200° to give benzenesulfonyl chloride as one product. Sulfonamides may be converted into sulfonyl chlorides by reaction with chlorosulfonic acid or phosphorus pentachloride. Benzenesulfondimethylamide[50] and *m*-nitrobenzenesulfonamide[51] behave this way with chlorosulfonic acid at 150° and N-benzenesulfonylglycine[52] is split by phosphorus pentachloride in acetyl chloride solution.

In the presence of aluminum chloride sulfuryl chloride[53a] reacts with benzene or toluene to give sulfonyl chlorides, sulfones occurring as byproducts. More recently it has been reported[53b] that heating *p*-chlorobenzenediazonium chloride in liquid sulfur dioxide gives an 80% yield of the sulfonyl chloride.

$$CH_3C_6H_5 + SO_2Cl_2 \xrightarrow{AlCl_3} p\text{-}CH_3C_6H_4SO_2Cl + HCl$$

$$p\text{-}ClC_6H_4N_2Cl + SO_2 \xrightarrow{CuCl_2} p\text{-}ClC_6H_4SO_2Cl + N_2\uparrow$$

Heating a salt of a sulfonic acid with benzotrichloride is reported[54] to yield the sulfonyl chloride.

$$C_6H_5SO_3Na + C_6H_5CCl_3 \rightarrow C_6H_5SO_2Cl + NaCl + C_6H_5COCl$$

In the following tables are listed the sulfonyl chlorides derived from the common aromatic nuclei. Under "Reagent," I refers to phosphorus pentachloride or rarely phosphorus oxychloride; II refers to chlorosulfonic acid; and III, one or more miscellaneous methods of preparation including substitution reactions already described in the preceding pages. The references for these latter already given are not repeated. Since the chlorides have almost always been converted into sulfonamides, by reaction with aqueous or alcoholic ammonia or ammonium carbonate, the melting points of these are also given in the tables. Many sulfonyl chlorides also have been converted into anilides. When the anilide is known its melting point and a superscript number indicating the reference from which this figure is derived are given in the last column. The methods for preparing amides and anilides are discussed more adequately in a later section. All references are given at the end of each table. In Table II are listed the monosulfonyl chlorides derived from benzene and its halogen and nitro derivatives. This is followed by tables listing sulfonyl chlorides obtained from other benzene derivatives and then from other ring systems including biphenyl, naphthalene, acenaphthene, anthracene, and phenanthrene derivatives.

TABLE II

BENZENE DERIVATIVES

			M.P., °C.	
Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	Amide	Anilide and Reference
C_6H_5-	I,[1] II,[2] III	14.5	153	112
4-FC_6H_4-	I,[3] II[61]	36	124–125	....
2-ClC_6H_4-	I[4]	28.5	188	....
3-ClC_6H_4-	I[5]	Oil	148	....
4-ClC_6H_4-	I,[6] II[7, 31]	53	143–144	104[59]
2,5-$Cl_2C_6H_3$-	I,[8] II[9, 67, 61, 66]	38	185–186 179.5–180	160[66]
2,4-$Cl_2C_6H_3$-	I,[8] II[61]	54.6, 52–53	182, 179–180	....
3,4-$Cl_2C_6H_3$-	I,[8] II[61]	22.4, 18–19	140, 134–135	....
2,3,4-$Cl_3C_6H_2$-	II[61, 68]	64–65	226–230 (dec.)	....
2,4,5-$Cl_3C_6H_2$-	II[10, 61, 68]	31–34	>200	....
2,4,6-$Cl_3C_6H_2$-	II[61]	35–40	210–212 (dec.)	....
2-BrC_6H_4-	I[11, 12]	51	186	....
3-BrC_6H_4-	I[13]	Oil	153–154	....
4-BrC_6H_4-	I,[14] II[61]	75–76	165, 161.5	....
5,2-$ClBrC_6H_3$-	I[15]	46	191	164[34, 35]
2,5-$ClBrC_6H_3$-	I[15]	66	178	138[34, 35]
2,4-$Br_2C_6H_3$-	I,[16, 17] II[61]	79–79.5	190, 188–189	....
2,5-$Br_2C_6H_3$-	I,[12, 18, 19, 20] II[61]	71	193, 194–195	143[34, 35]
3,4-$Br_2C_6H_3$-	I,[16, 19] II[61]	34	175	....
3,5-$Br_2C_6H_3$-	I[21, 22]	57.5	203	....
4,3,5-$ClBr_2C_6H_2$-	I[23]	94.5	....	....
2,3,5-$Br_3C_6H_2$-	I[21]	86	225 (dec.)	....
2,4,5-$Br_3C_6H_2$-	I[16, 20]	86.5	225 (dec.)	....
2,4,6-$Br_3C_6H_2$-	I,[24, 25] II[61]	64.5, 58–60	228 (dec.)	220–222 (dec.)
3,4,5-$Br_3C_6H_2$-	I[21, 26]	127	210	....
2,3,4,5-Br_4C_6H-	I[27, 28]	120	240 (dec.)	....
2,3,4,6-Br_4C_6H-	I[25a, 29, 30]	96.5	>240 (dec.)	....
Br_5C_6-	I[31]	153–154	>290	....
2-IC_6H_4-	I[4a, 33, 72]	51	170	....
3-IC_6H_4-	I[32]	23	153	....
4-IC_6H_4-	I,[3, 14b, 33] III	84–85	183	143[60]
2,5-$IClC_6H_3$-	I[34, 35]	69	....	168[34, 35]
3,6-$IClC_6H_3$-	I[35]	143	....	....
2,5-$IBrC_6H_3$-	I[36]	97	....	150[34, 36]
3,6-$IBrC_6H_3$-	I[36]	91	....	....
2,4-$I_2C_6H_3$-	I[36]	77–78	230	....
2,5-$I_2C_6H_3$-	I[36]	131–132	....	....
3,4-$I_2C_6H_3$-	I[36]	82	227	....
3,5-$I_2C_6H_3$-	I[36]	93	205–218	....
2,3,5-$I_3C_6H_2$-	I[36]	122–123	>280	....
2,4,5-$I_3C_6H_2$-	I[36]	135	>260	194–196[36]
3,4,5-$I_3C_6H_2$-	I[36]	145	>250	201[36]

TABLE II (*Continued*)

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C.	
			Amide	Anilide and Reference
2,3,4,5-I_4C_6H-	I[37]	161–162	....	....
2-$O_2NC_6H_4$-	I,[36, 38, 39] III[58, 70]	68.5–69.5	193	115[63]
3-$O_2NC_6H_4$-	I,[39, 40] II,[41] III[63]	63–64	167–168	125[63]
4-$O_2NC_6H_4$-	I,[39, 42, 64, 67, 69] III	80.5	179–180	171[63]
4,2-Cl(O_2N)C_6H_3-	I[67]	....	....	....
5,2-Cl(O_2N)C_6H_3-	I[43]	....	158–159	....
6,2-Cl(O_2N)C_6H_3-	I[44]	180	Dec.	....
4,3-Cl(O_2N)C_6H_3-	I[45, 65]	40–41	175–176	....
5,3-Cl(O_2N)C_6H_3-	I[44]	Oil	164–165	....
6,3-Cl(O_2N)C_6H_3-	I,[45, 46] II[66]	89–90	185–186	....
2,5,3-Cl_2(O_2N)C_6H_2-	III[56]	59–60	....	....
4,3,5-Cl$(O_2N)_2C_6H_2$-	II[65]	89	....	....
4,2-Br(O_2N)C_6H_3-	I[42b]	100	....	....
5,2-Br(O_2N)C_6H_3-	I[47]	83	169–170	....
2,3-Br(O_2N)C_6H_3-	I[48]	97	215	....
4,3-Br(O_2N)C_6H_3-	I[49]	56–57	176–177	....
6,3-Br(O_2N)C_6H_3-	I[48]	92	205	....
3,5,2-Br_2(O_2N)C_6H_2-	I[21]	118–121	Dec. 300°	....
4,5,2-Br_2(O_2N)C_6H_2-	I[26]	98–99	210–211	....
4,6,3-Br_2(O_2N)C_6H_2-	I[17]	115.5	Dec. 200°	....
2,5,3-Br_2(O_2N)C_6H_2-	I[50]	Oil	178	....
3,4,5,2-Br_3(O_2N)C_6H-	I[28]	116	202	....
2,4,5,3-Br_3(O_2N)C_6H-	I[27]	143	250	....
2,4,6,3-Br_3(O_2N)C_6H-	I[25a, 30]	144–145	182	....
3,4,5,6,2-Br_4(O_2N)C_6-	I[27]	172–173	260 (dec.)	....
2,4,5,6,3-Br_4(O_2N)C_6-	I[51]	147.5	....	....
2,5-I(O_2N)C_6H_3-	I[71]	122–123	....	....
2,4-$(O_2N)_2C_6H_3$-	I,[52] III[62]	102	154, 156–157	....
3,5-$(O_2N)_2C_6H_3$-	I[53]	98–99	235	....
4,3,5-Cl$(O_2N)_2C_6H_2$-	I[54]	89	....	....
2,4,6,3,5-$Br_3(O_2N)_2C_6$-	I[55]	200 (dec.)	255–260 (dec.)	....

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[1] Gerhardt and Chiozza, *Ann.*, **87**, 299 (1853); Otto, *Ann.*, **141**, 366 (1867); Vogt, *Ann.*, **119**, 143 (1861); Barbaglia and Kekulé, *Ber.*, **5**, 876 (1872); Bourgeois, *Rec. trav. chim.*, **18**, 432 (1899); Mohrmann, *Ann.*, **410**, 379 (1915); Rosenmund and Struck, *Ber.*, **54**, 439 (1921); *Org. Syntheses, Coll. Vol. I*, John Wiley & Sons, New York, 1932, p. 77; Kershner and Turner, *Science*, **58**, 184 (1920).

[2] See references under sulfonation of benzene, Chapter III.

[3] Lenz, *Ber.*, **18**, 581 (1879); **10**, 1137 (1877).

[4] (*a*) Bahlmann, *Ann.*, **186**, 325 (1877). (*b*) Limpricht, *Ann.*, **180**, 110 (1876).

[5] Paal, *Ber.*, **34**, 2755 (1901); Kieselinsky, *Ann.*, **180**, 110 (1876).

[6] Otto, *Ann.*, **143**, 106 (1867); Goslich, *Ann.*, **180**, 106 (1876).

[7] Ullmann and Korselt, *Ber.*, **40**, 642 (1907); Beckurts and Otto, *Ber.*, **11**, 2064 (1878); Pummerer, *Ber.*, **42**, 1802 (1909).

[8] Holleman and van der Linden, *Rec. trav. chim.*, **30**, 331 (1911).

[9] Stewart, *J. Chem. Soc.*, **121**, 2555 (1922).

[10] Woods, this laboratory, unpublished results.

[11] Berndsen and Limpricht, *Ann.*, **177**, 101 (1875).

[12] Bahlmann, *Ann.*, **181**, 206 (1876).

[13] Berndsen, *Ann.*, **177**, 94 (1875).

[14] (a) Hübner and Alsberg, *Ann.*, **156**, 326 (1870). (b) Mummery, *Proc. Roy. Soc.*, **90A**, 455 (1914). (c) Nölting, *Ber.*, **8**, 598 (1875).

[15] Armstrong and Briggs, *Chem. News*, **66**, 138 (1892).

[16] Langfurth, *Ann.*, **191**, 184 (1878).

[17] Bässmann, *Ann.*, **191**, 234 (1878).

[18] Thomas, *Ann.*, **186**, 131 (1877).

[19] Limpricht, *Ann.*, **186**, 138 (1877).

[20] Rosenberg, *Ber.*, **19**, 653 (1886); Reinke, *Ann.*, **186**, 290 (1877).

[21] Lenz, *Ann.*, **181**, 28 (1876).

[22] Limpricht, *Ann.*, **181**, 202 (1876).

[23] Anschütz and Molineus, *Ann.*, **415**, 61 (1918).

[24] Reinke, *Ann.*, **186**, 277 (1877).

[25] (a) Knuth, *Ann.*, **186**, 295 (1877). (b) Hantzsch and Voegelen, *Ber.*, **34**, 3159 (1901).

[26] Goslich, *Ann.*, **186**, 154 (1877).

[27] Spiegelberg, *Ann.*, **197**, 295 (1879).

[28] Lenz, *Ann.*, **181**, 46 (1876).

[29] Beckurts, *Ann.*, **181**, 219 (1876).

[30] Bässmann, *Ann.*, **191**, 227 (1878).

[31] Heinzelmann and Spiegelberg, *Ann.*, **197**, 311 (1879).

[32] Langmuir, *Ber.*, **28**, 95 (1895).

[33] Tröger and Hurdelbrink, *J. prakt. Chem.*, [2] **65**, 83 (1902).

[34] Colgate and Rodd, *Chem. News*, **100**, 222 (1909).

[35] Colgate and Rodd, *J. Chem. Soc.*, **97**, 1600 (1910).

[36] Boyle, *ibid.*, **95**, 1697–1716 (1909).

[37] Boyle, *ibid.*, **99**, 333 (1911).

[38] Limpricht, *Ann.*, **177**, 77 (1875); Ekbom, *Bihang till Svenska Vet.-Akad. Handlinger*, **27**, II, No. 1, 17; Ullmann and Gross, *Ber.*, **43**, 2700 (1910); Claasz, *Ann.*, **380**, 312 (1911).

[39] Obermiller, *J. prakt. Chem.*, [2] **89**, 84 (1914).

[40] Glutz and Schrank, *ibid.*, [2] **2**, 223 (1870); Biedermann, *Ber.*, 8, 1675 (1873).

[41] Chem. Fabr. von Heyden, German pat., 89,997, *Frdl.*, **4**, 39; see, however, Pollak, Heimberg-Krauss, Katscher, and Lustig, *Monatsh.*, **55**, 358 (1930).

[42] (a) Ekbom, *Ber.*, **35**, 653 (1902). (b) Blanksma, *Rec. trav. chim.*, **20**, 129 (1901).

[43] Laubenheimer, *Ber.*, **15**, 599 (1882).

[44] Claus and Bopp, *Ann.*, **265**, 101 (1891).

[45] Fischer, *Ber.*, **24**, 3190 (1891).

[46] Claus and Mann, *Ann.*, **265**, 91 (1891).

[47] Thomas, *Ann.*, **186**, 126 (1877).

[48] Bahlmann, *Ann.*, **186**, 323 (1877).

[49] Goslich, *Ann.*, **180**, 100 (1876); Andrews, *Ber.*, **13**, 2128 (1880).

[50] Borns, *Ann.*, **187**, 361 (1877).

[51] Langfurth, *Ann.*, **191**, 203 (1878).

[52] Willgerodt and Mohr, *J. prakt. Chem.*, [2] **34**, 123 (1886).

[53] Sachse, *Ann.*, **188**, 147 (1877); Jackson and Earle, *Am. Chem. J.*, **29**, 219 (1903); Limpricht, *Ber.*, 9, 554 (1876).

[54] Ullmann and Kuhn, *Ann.*, **366**, 104 (1909).

[55] Bässmann, *Ann.*, **191**, 243 (1878).

[56] Gebauer-Fülnegg and Neumann, *Monatsh.*, **50**, 235 (1928).

[57] Gebauer-Fülnegg and Figdor, *ibid.*, **48**, 627 (1927).

[58] Fierz, Schlittler, and Waldmann, *Helv. Chim. Acta*, **12**, 663 (1929).

[59] Wallach and Huth, *Ber.*, 9, 426 (1876).

[60] Ullmann and Loewenthal, *Ann.*, **332**, 58 (1904).

[61] Huntress and Carten, *J. Am. Chem. Soc.*, **62**, 511 (1940).

[62] Sprague and Johnson, *ibid.*, **59**, 2439 (1937).

[63] Bennett and Youle, *J. Chem. Soc.*, 887 (1938).

[64] Alber, *J. Franklin Inst.*, **228**, 177 (1939).

[65] Pollak, Heimberg-Krauss, Katscher, and Lustig, *Monatsh.*, **55**, 358 (1930).

[66] Gebauer-Fülnegg, Riesz, Lorenz, and Pollak, *ibid.*, **48**, 645 (1927).

[67] Witte, *Rec. trav. chim.*, **51**, 299 (1932).

[68] Herz, Runne, and Albrecht, U. S. pat., 1,763,556, *C.A.*, **24**, 3800 (1930).

[69] Bell, *J. Chem. Soc.*, 2770 (1928).

[70] Wertheim, *Org. Syntheses*, **15**, 55 (1935).

[71] Lesslie and Turner, *J. Chem. Soc.*, 2021 (1932).

[72] Schwarzenbach and Egli, *Helv. Chim. Acta*, **17**, 1176 (1934).

TABLE III

BENZENE DERIVATIVES

Aryl Group of Di- and Trisulfonyl Chlorides	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C.	
			Amide	Anilide and Reference
C_6H_4-1,2-	I[1, 2]	143	252	241[1]
C_6H_4-1,3-	I,[3, 2] II,[4, 27] III	63.5	229	148–150[20–24]
C_6H_4-1,4-	I,[2, 3a, 5, 6] II,[4] III[30]	138–139	288	248–249[23, 25, 26]
4-ClC_6H_3-1,2-	III[31]	82–83	....	....
4-ClC_6H_3-1,3-	I,[7] II,[4, 27] III[33]	90.5, 88	217–219	....
5-ClC_6H_3-1,3-	I[8]	105.5–106	223–224	....
2-ClC_6H_3-1,4-	I[35]	96.5–97	....	....
4,6-$Cl_2C_6H_2$-1,3-	I,[9] III[34]	122–123	276	....
2,5-$Cl_2C_6H_2$-1,3-	II[10, 29]	114	....	215–217[29]
2,5-$Cl_2C_6H_2$-1,4-	H[10, 29]	182	....	....
2,4,6-Cl_3C_6H-1,3-	I[9]	161.5	....	....
4,5,6-Cl_3C_6H-1,3-	III[34]	175	....	100–110
4-BrC_6H_3-1,2-	I[1]	88	....	182[1]
4-BrC_6H_3-1,3-	I[11]	103–105	239	....
5-BrC_6H_3-1,3-	I[12, 19]	99–100	245; 255–256	....
2-BrC_6H_3-1,4-	I[13]	104	210	....
2,5-$Br_2C_6H_2$-1,4-	I,[14] III	165	240	....
4-$O_2NC_6H_3$-1,3-	I[15]	Oil	....	....
5-$O_2NC_6H_3$-1,3-	I[15, 22]	96	242	
4,5-$Cl(O_2N)C_6H_2$-1,3-	II[4]	98	....	....
4,6-$Cl(O_2N)C_6H_2$-1,3(?)-	I[16]	Impure	....	....
3,5-$(O_2N)_2C_6H_2$-1,4-	I[17]	Dec.	Dec.	....
C_6H_3-1,3,5-	I,[5, 18] III	184	346–347 (dec.)	....
2-ClC_6H_2-1,3,5-	III[28, 33]	170–171	....	....

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[1] Armstrong and Napper, *Chem. News*, **82**, 46 (1900).

[2] Pollak, *Rec. trav. chim.*, **29**, 427 (1910).

[3] (*a*) Körner and Monselise, *Gazz. chim. ital.*, **6**, 139 (1876); *Ber.*, **9**, 584 (1876). (*b*) Passchke, *J. prakt. Chem.*, [2] **8**, 418 (1870); Nölting, *Ber.*, **8**, 1113 (1875).

[4] Pollak, Heimberg-Krauss, Katscher, and Lustig, *Monatsh.*, **55**, 358 (1930).

[5] Jackson and Wing, *Am. Chem. J.*, **9**, 332 (1887).

[6] Armstrong, Colgate, and Rodd, *Proc. Roy. Soc.*, **90A**, 161 (1914).

[7] Olivier, *Rec. trav. chim.*, **38**, 353 (1919).

[8] Olivier, *ibid.*, **37**, 309 (1918).

[9] Davies and Poole, *J. Chem. Soc.*, 1122 (1927).

[10] Gebauer-Fülnegg and Figdor, *Monatsh.*, **48**, 627 (1927).

[11] Meyer and Nölting, *Ber.*, **7**, 1311 (1874); Heinzelmann, *Ann.*, **190**, 228 (1878); Zander, *Ann.*, **198**, 11 (1879).

[12] Heinzelmann, *Ann.*, **188**, 177 (1877).

[13] Zander, *Ann.*, **198**, 29 (1879).

[14] Borns, *Ann.*, **187**, 355 (1877).

[15] Heinzelmann, *Ann.*, **188**, 166 (1877).

[16] Allert, *Ber.*, **14**, 1436 (1881).

[17] Limpricht, *Ber.*, **8**, 289 (1875).

[18] Behrend and Mertelsmann, *Ann.*, **378**, 362 (1911).

[19] Olivier and de Kleermaeker, Jr., *Rec. trav. chim.*, **39**, 640 (1920).

[20] Troeger and Meine, *Ber.*, **35**, 1959 (1902).

[21] Chattaway, *J. Chem. Soc.*, **85**, 1187 (1904).
[22] Autenrieth and Hennings, *Ber.*, **35**, 1396 (1902).
[23] Armstrong, Colgate, and Rodd, *Chem. Zentr.*, 1, 2000 (1914).
[24] Zincke and Krüger, *Ber.*, **45**, 3471 (1912).
[25] Zincke and Frohneberg, *Ber.*, **42**, 2728 (1909).
[26] Schultz, *Ber.*, **39**, 3347 (1906).
[27] Soc. pour l'ind. chim. à Bâle, French pat., 825,728, *C.A.*, **32**, 6667 (1938).
[28] Pollak *et al.*, *Monatsh.*, **39**, 179 (1918).
[29] Gebauer-Fülnegg, Riesz, Lorenz, and Pollak, *ibid.*, **48**, 645 (1927).
[30] Parekh and Guha, *J. Ind. Chem. Soc.*, 11, 95 (1934).
[31] Mills and Clark, *J. Chem. Soc.*, 175 (1936).
[32] Bennett and Willis, *ibid.*, 256 (1929).
[33] Riesz, Berndt, and Hitschmann, *Monatsh*, **50**, 328 (1928).
[34] Pollak and Gebauer-Fülnegg, *ibid.*, **46**, 499 (1926).
[35] Olivier, *Rec. trav. chim.*, **39**, 495 (1920).

TABLE IV

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C. Amide	M.P., °C. Anilide and Reference
		A. Alkylbenzene Derivatives		
2-$CH_3C_6H_4$-	I,[1] II,[2, 3] III	10	156.3	136[39]
3-$CH_3C_6H_4$-	I[3, 4]	11.7	108	96[4a]
4-$CH_3C_6H_4$-	I,[6] II,[2, 6] III	69	137	103
2-$C_2H_5C_6H_4$-	I[7, 8]	Oil	99–100	....
3-$C_2H_5C_6H_4$-	I[8]	....	85–86	....
4-$C_2H_5C_6H_4$-	I[7, 8, 9]	12	110	....
2-*n*-$C_3H_7C_6H_4$-	I[10]	....	128	....
3-*n*-$C_3H_7C_6H_4$-	I[10]	....	57	....
4-*n*-$C_3H_7C_6H_4$-	I[10, 11]	....	110	....
4-*iso*-$C_3H_7C_6H_4$-	I[11, 12]	....	106.5–107	....
4-*sec*-$C_4H_9C_6H_4$-	I[13]	Oil, b.p. 179–180/ 20 mm.	80–81	63–64[13]
4-*tert*-$C_4H_9C_6H_4$-	I[14]	....	137	....
4-*n*-$C_6H_{11}C_6H_4$-	I[54]	38–39	86–87	....
4-[(*n*-C_3H_7)(CH_3)CH]-C_6H_4-	I[15]	B.p.194 (12 mm.)	66–67	60–61[15]
4-$(C_2H_6)_2CHC_6H_4$-	I[16]	....	89–90	....
4-$(CH_3)_3CCH_2C_6H_4$-	I[53]	58.7–59.2	101	137[53]
		B. Halo and Nitroalkylbenzene Derivatives		
4,2-$F(CH_3)C_6H_3$-	II[44]	Oil	172–173	....
5,2-$F(CH_3)C_6H_3$-	I,[16] II[17, 44]	B.p. 145-150 (20 mm.)	....	....
4,3-$F(CH_3)C_6H_3$-	II[44]	Oil	104–105	....
2-$(ClCH_2)C_6H_4$-	III[52]	46	....	....
3,2-$Cl(CH_3)C_6H_3$-	III[31]	72	180	....
4,2-$Cl(CH_3)C_6H_3$-	I,[47] II[44, 46]	52–54	184–185	....
5,2-$Cl(CH_3)C_6H_3$-	I[18]	24, 21	142–143; 145	144[34, 40]
4,3-$Cl(CH_3)C_6H_3$-	I,[18] II[44]	63	126–128	92[34]
6,3-$Cl(CH_3)C_6H_3$-	I[34]	56	156	188[34]
4-$(ClCH_2)C_6H_4$-	III[52]	56	....	....

TABLE IV (*Continued*)

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C. Amide	M.P., °C. Anilide and Reference
		B. Halo and Nitroalkylbenzene Derivatives (Continued)		
2,4-$Cl(CH_3)C_6H_3$-	I[47]	46	186	....
3,4-$Cl(CH_3)C_6H_3$-	III[24, 31, 51]	38	134	96[34]
3,4,2-$Cl_2(CH_3)C_6H_2$-	I[47]	51–52	228	....
3,5,2-$Cl_2(CH_3)C_6H_2$-	I[48]	54	186	....
3,6,2-$Cl_2(CH_3)C_6H_2$-	I[48]	38	180	....
4,6,2-$Cl_2(CH_3)C_6H_2$-	I[47]	43	168	....
5,6,2-$Cl_2(CH_3)C_6H_2$-	I[48]	49	186	....
2,4,3-$Cl_2(CH_3)C_6H_2$-	II[44, 46, 47]	54–56, 59, 60	199–201	203[44, 47]
2,6,3-$Cl_2(CH_3)C_6H_2$-	I[48]	19.5	188	....
4,5,3-$Cl_2(CH_3)C_6H_2$-	I[25, 47]	85, 88	183–185	....
4,6,3-$Cl_2(CH_3)C_6H_2$-	I,[25] II[44, 47, 49]	71–72	175–176, 178	....
5,6,3-$Cl_2(CH_3)C_6H_2$-	I[48]	64	158	....
2,3,4-$Cl_2(CH_3)C_6H_2$-	I[47]	40–41	237	....
2,5,4-$Cl_2(CH_3)C_6H_2$-	I[25b, 29]	45–46	191–192	....
2,6,4-$Cl_2(CH_3)C_6H_2$-	I[47]	56	154–155	....
3,5,4-$Cl_2(CH_3)C_6H_2$-	I,[48] III[31]	69	191	....
3,6,4-$Cl_2(CH_3)C_6H_2$-	III[31]	....	....	....
2,3,4,6-$Cl_3(CH_3)C_6H$-	I[18a]	88	....	....
4,2-$Br(CH_3)C_6H_3$-	I,[20] II[44]	49–50	162–165; 167–168	....
5,2-$Br(CH_3)C_6H_3$-	I,[19] II[44]	33–35	166–167; 164–165	....
4,3-$Br(CH_3)C_6H_3$-	I,[27, 28, 29] II[44]	59–61	145–147	....
5,3-$Br(CH_3)C_6H_3$-	I[28, 27]	52–53	138–139	....
6,3-$Br(CH_3)C_6H_3$-	I[19, 26, 27]	61–62	151–152	....
2,4-$Br(CH_3)C_6H_3$-	III	80	....	....
3,4-$Br(CH_3)C_6H_3$-	I,[32] III	60	151	....
4,5,3-$Br_2(CH_3)C_6H_2$-	I[29]	93	214	....
*1,2,4-$CH_3(Br_2)C_6H_2$-	I[38]	86–88	212–213	....
*1,2,5-$CH_3(Br_2)C_6H_2$-	I[38]	73–74	210–211	....
*1,2,6-$CH_3(Br_2)C_6H_2$-	I[38]	101	204	....
*1,3,4-$CH_3(Br_2)C_6H_2$-	I[38]	104–105	212	....
*1,3,5-$CH_3(Br_2)C_6H_2$-	I[38]	Oil	195	....
2,3,6,4-$Br_3(CH_3)C_6H$-	I[38]	Oil	Dec.	....
*1,2,3-$CH_3(Br)(Cl)C_6H_2$-	I[37]	70–71	224	....
*1,2,4-$CH_3(Br)(Cl)C_6H_2$-	I[37]	84	186	....
*1,2,5-$CH_3(Br)(Cl)C_6H_2$-	I[37]	49–50	201	....
*1,2,6-$CH_3(Br)(Cl)C_6H_2$-	I[37]	70	205	....
*1,3,2-$CH_3(Br)(Cl)C_6H_2$-	I[37]	81–84	200–201	....
*1,3,4-$CH_3(Br)(Cl)C_6H_2$-	I[37]	87–88	204.5	....
*1,3,5-$CH_3(Br)(Cl)C_6H_2$-	I[37]	Oil	178	....
*1,3,6-$CH_3(Br)(Cl)C_6H_2$-	I[37]	45–46	192	....
*1,4,2-$CH_3(Br)(Cl)C_6H_2$-	I[37]	79	186	....
*1,4,3-$CH_3(Br)(Cl)C_6H_2$-	I[37]	101	191–192	....

* The position of the sulfonyl group is uncertain. The relative positions of the halogens and the methyl group are given.

TABLE IV (*Continued*)

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C.	
			Amide	Anilide and Reference
B. Halo and Nitroalkylbenzene Derivatives (*Continued*)				
5,2-$Br(C_2H_6)C_6H_3$-	I^{8}	....	123–124	....
4,3-$Br(C_2H_5)C_6H_3$-	I^{8}	....	104	....
5,2-$I(CH_3)C_6H_3$-	$I^{16, 21}$	....	185–187	....
2,5-$I(CH_3)C_6H_3$-	I^{45}	68	161–162	....
4-$(ICH_2)C_6H_4$-	III^{52}	106	....	....
3,2-$O_2N(CH_3)C_6H_3$-	I^{50}	....	165	....
5,2-$O_2N(CH_3)C_6H_3$-	$I,^{22}$ II^{23}	43–44.5	186–187	148^{41}
2,3-$O_2N(CH_3)C_6H_3$-	I^{30}	58.5	163.5	....
4,3-$O_2N(CH_3)C_6H_3$-	I^{30}	50	133.5	....
2,4-$O_2N(CH_3)C_6H_3$-	III^{43}	98–99	170	129^{43}
3,4-$O_2N(CH_3)C_6H_3$-	$I,^{5a, d; 34}$ $II,^{22c}$ III^{35}	36	142.5, 144	109^{42}
5,3,2-$Cl(O_2N)(CH_3)C_6H_2$-	$I,^{48}$ III^{48}	60	167	....
5,6,2-$Cl(O_2N)(CH_3)C_6H_2$-	$I,^{48}$ III^{48}	154	183	....
4,5,2-$Cl(O_2N)(CH_3)C_6H_2$-	$I,^{48}$ III^{48}	116	170	....
4,3,2-$Cl(O_2N)(CH_3)C_6H_2$-	$I,^{48}$ III^{48}	96	176	....
4,5,3-$Cl(O_2N)(CH_3)C_6H_2$-	$I,^{49}$ III^{18b}	52	201	....
4,6,3-$Cl(O_2N)(CH_3)C_6H_2$-	I^{49}	97	172	....
6,2,3-$Cl(O_2N)(CH_3)C_6H_2$-	$I,^{48}$ III^{48}	122	177	....
6,4,3-$Cl(O_2N)(CH_3)C_6H_2$-	I^{48}	92	188	....
6,5,3-$Cl(O_2N)(CH_3)C_6H_2$-	$I,^{48}$ III^{48}	62.5	196	....
3,5,4-$Cl(O_2N)(CH_3)C_6H_2$-	$I,^{49}$ $III^{31c, 49}$	70	182	....
3,6,4-$Cl(O_2N)(CH_3)C_6H_2$-	$I,^{49}$ $III^{31a, 49}$	99	181	....
5,2,4-$Br(O_2N)(CH_3)C_6H_2$-	I^{33}	>220(?)	>200	....
3,5,4-$(O_2N)_2(CH_3)C_6H_2$-	I^{35}	125	203	....
3,5,2-$(O_2N)_2(CH_3)C_6H_2$-	I^{50}	107	....	....

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[1] Hübner and Terry, *Ann.*, **169**, 29 (1873); Jenssen, *Ann.*, **179**, 236 (1874).

[2] Claësson and Wallin, *Ber.*, **12**, 1849 (1879); Noyes, *Am. Chem. J.*, **8**, 176 (1886); Houmann, *Ber.*, **17**, 1114 (1884); Harding, *J. Chem. Soc.*, **119**, 1261 (1921); McKie, *ibid.*, **118**, 799 (1918); Monsanto Chemical Co., German pat., 640,650, *C.A.*, **31**, 5383 (1937); Inozemtsev, *Org. Chem. Ind.* (*U.S.S.R.*), 8, 296 (1937); *C.A.*, **51**, 7046 (1937); Kreidl, Austrian pat., 110,128, *C.A.*, **23**, 1138 (1929).

[3] Holleman and Caland, *Ber.*, **44**, 2505 (1911).

[4] (*a*) Griffin, *Am. Chem. J.*, **19**, 190 (1897). (*b*) Hübner and Müller, *Ann.*, **169**, 50 (1873).

[5] (*a*) Wolkowa, *J. Russ. Phys.-Chem. Soc.*, **2**, 165 (1870), *Z. Chem.*, 323, (1870). (*b*) Bourgeois, *Rec. trav. chim.*, **18**, 436 (1899). (*c*) Kershner and Turner, *Science*, **52**, 184 (1920). (*d*) Jaeger, *Proc. Acad. Sci. Amsterdam*, **23**, 347 (1920).

[6] Gilliard, Monnet, and Cartier, German pat., 98,030, *Frdl.*, **4**, 1261.

[7] Moody, *Chem. News*, **71**, 197 (1895).

[8] Sempotowski, *Ber.*, **22**, 2672 (1889).

[9] Chruschtschow, *Ber.*, **7**, 1166 (1874); Moschner, *Ber.*, **34**, 1261 (1901).

[10] Moody, *Chem. News*, **79**, 81 (1899).

[11] Meyer and Baur, *Ann.*, **219**. 298 (1883).

[12] Spica, *Gazz. chim. ital.*, 9, 439 (1879).

[13] Klages, *Ber.*, **39**, 2133 (1906).

[14] Kelbe and Pfeiffer, *Ber.*, 19, 1728 (1886).

[15] Klages, *Ber.*, **36**, 3590 (1903).

[16] de Roode, *Am. Chem. J.*, **13**, 224 (1891).

[17] Holleman, *Rec. trav. chim.*, **25**, 332 (1906).

[18] (*a*) Wynne, *J. Chem. Soc.*, **61**, 1070 (1892). (*b*) Davies and Davies, *ibid.*, **123**, 2976 (1923).

[19] Hübner, Rotschy, Hässelbarth, and Post, *Ann.*, **169**, 6, 15 (1873).

[20] Weckworth, *Ann.*, **172**, 196 (1874).

[21] Glassner, *Ber.*, **8**, 561 (1875).

[22] (*a*) Ullmann and Lehner, *Ber.*, **38**, 736 (1905). (*b*) Green, Marsden, and Scholefield, *J. Chem. Soc.*, **85**, 1432 (1904). (*c*) Chem. Fabr. von Heyden, German pat., 89,997, *Frdl.*, **4**, 39.

[23] Jenssen, *Ann.*, **172**, 232 (1874); Noyes, *Am. Chem. J.*, **8**, 168 (1886).

[24] Wynne and Bruce, *J. Chem. Soc.*, **73**, 739–772 (1898).

[25] (*a*) Wynne and Greeves, *Chem. News*, **72**, 58 (1895). (*b*) Cohen and Dakin, *J. Chem. Soc.*, **79**, 1129 (1901).

[26] v. Pechmann, *Ann.*, **173**, 208 (1874).

[27] Nevile and Winther, *J. Chem. Soc.*, **37**, 631 (1880); *Ber.*, **13**, 1947 (1880).

[28] Hübner, Retschy, Müller, and Post, *Ann.*, **169**, 40 (1873); Pagel, *Ann.*, **176**, 296 (1875).

[29] Wynne, *J. Chem. Soc.*, **61**, 1042 (1892).

[30] Foth, *Ann.*, **230**, 308 (1885).

[31] (*a*) Ges. für Chem. Ind., German pat., 133,000, *Chem. Zentr.*, II, 313 (1902). (*b*) Limpricht and Paysan, *Ann.*, **221**, 213 (1883). (*c*) Davies, *J. Chem. Soc.*, **119**, 853 (1921).

[32] Hayduck, *Ann.*, **172**, 206 (1874).

[33] Hayduck, *Ann.*, **174**, 355 (1874).

[34] Otto and Gruber, *Ann.*, **145**, 23 (1868); Fichter and Bernoulli, *Ber.*, **42**, 4309 (1909).

[35] Reverdin and Crépieux, *Bull. soc. chim.*, [3] **25**, 1040 (1901); *Ber.*, **34**, 2992 (1901); Holleman, *Rec. trav. chim.*, **24**, 198 (1905).

[36] Schwanert, *Ann.*, **186**, 359 (1877).

[37] Cohen and Smithells, *J. Chem. Soc.*, **105**, 1909 (1914).

[38] Cohen and Dutt, *ibid.*, **105**, 502 (1914).

[39] Remsen and Kohler, *Am. Chem. J.*, **17**, 339–347 (1895); Tröger and Uhlmann, *J. prakt. Chem.*, [2] **51**, 437 (1895); Müller and Weisinger, *Ber.*, **12**, 1348 (1879).

[40] Groth, *Chem. Kryst.*, **5**, 75 (1919).

[41] Ullmann and Gschwind, *Ber.*, **41**, 2293 (1908).

[42] Reverdin and Crépieux, *Bull. soc. chim.*, [3] **25**, 1048 (1901); *Ber.*, **34**, 3001 (1901).

[43] Zincke and Röse, *Ann.*, **406**, 135 (1914).

[44] Huntress and Carten, *J. Am. Chem. Soc.*, **62**, 513 (1940).

[45] Barber and Smiles, *J. Chem. Soc.*, 1141 (1928).

[46] Herz, Bauer, Steiger, Albrecht, and Dereser, German pat., 555,140, *C.A.*, **26**, 5105 (1932).

[47] Silvester and Wynne, *J. Chem. Soc.*, 691 (1936).

[48] Wynne, *ibid.*, 696 (1936).

[49] Turner and Wynne, *ibid.*, 707 (1936).

[50] Hirwe and Jambhekar, *J. Indian Chem. Soc.*, **11**, 239 (1934).

[51] Villiger, *Ber.*, **61B**, 2596 (1928).

[52] Davies and Dick, *J. Chem. Soc.*, 2042 (1932).

[53] Bygdén, *J. prakt. Chem.*, [2] **100**, 1 (1919).

[54] Radcliffe and Simpkin, *J. Soc. Chem. Ind.*, **40**, 119 (1921).

TABLE V

Alkylbenzene Derivatives

Aryl Group of Di- and Tri-sulfonyl Chlorides	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C. Amide	M.P., °C. Anilide and Reference
4-$CH_3C_6H_3$-1,2-	I,[5] III[15]	109–111	235–239	190[6]
2-$CH_3C_6H_3$-1,3-	I[6, 7]	88	>260	162[6]
4-$CH_3C_6H_3$-1,3-	I,[1] II,[2, 17] III	53–54	186–187	187–189[6, 15, 16]
5-$CH_3C_6H_3$-1,3-	I[8, 9, 10]	94	216	153[6]
2-$CH_3C_6H_3$-1,4-	I[4, 5]	98	224	178[6]
4,5-$CH_3(Cl)C_6H_2$-1,2-	I[6]	158	....	183[6]
2,5-$CH_3(Cl)C_6H_2$-1,3-	I[6]	108	....	188[6]
4,5-$CH_3(Cl)C_6H_2$-1,3-	I[6]	88	....	180[6]
5,2-$CH_3(Cl)C_6H_2$-1,3-	I[11]	118	....	184[6]

TABLE V (*Continued*)

Aryl Group of Di- and Tri-sulfonyl Chlorides	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C. Amide	M.P., °C. Anilide and Reference
5,4-$CH_3(Cl)C_6H_2$-1,3-	I,[11] III[19]	85; 78	....	183[6]
6,4-$CH_3(Cl)C_6H_2$-1,3-	III[19]	125	....	....
2,5-$CH_3(Cl)C_6H_2$-1,4-	I[4]	144	....	245[6]
2,5-$CH_3(Br)C_6H_2$-1,3-	I[7]	99 (dec.)	>260	....
5,2-$CH_3(Br)C_6H_2$-1,3-	I[10]	133	>240	....
5,4-$CH_3(Br)C_6H_2$-1,3-	I[4, 12]	102	236–238	194[6]
5,2-$CH_3(I)C_6H_2$-1,3-	I[10]	143	130–132(?)	....
4-$C_2H_5C_6H_3$-1,3-	I[13]	Oil	186–190	....
2-$CH_3C_6H_2$-1,3,5-	I,[14] III	153	>300	....
2,4-$CH_3(Cl)C_6H$-1,3,5-	III[19]	161	....	....

[1] Gnehm and Forrer, *Ber.*, **10**, 543 (1877); Fallberg, *Am. Chem. J.*, **2**, 183 (1880).
[2] Pollak, Heimberg-Krauss, Katscher, and Lustig, *Monatsh.*, **55**, 358 (1930).
[3] Pope, *J. Chem. Soc.*, **73**, 776 (1898).
[4] Wynne and Bruce, *ibid.*, **73**, 743, 758 (1898).
[5] Klason, *Ber.*, **19**, 2888 (1886).
[6] Wynne and Bruce, *J. Chem. Soc.*, **73**, 739–771 (1898).
[7] Kornatzki, *Ann.*, **231**, 200 (1883).
[8] Klason, *Ber.*, **10**, 656 (1877); Wynne and Bruce, *J. Chem. Soc.*, **73**, 752 (1898).
[9] Pope, *ibid.*, **73**, 747 (1898).
[10] Richter, *Ann.*, **230**, 327 (1885).
[11] Pope, *J. Chem. Soc.*, **73**, 742 (1898).
[12] Hasse, *Ann.*, **230**, 295 (1885).
[13] Pollak, Fiedler, and Roth, *Monatsh.*, **39**, 184 (1918).
[14] Claësson, *Ber.*, **14**, 309 (1881).
[15] Troeger and Meine, *Ber.*, **35**, 1959 (1902).
[16] Pope, *J. Chem. Soc.*, **73**, 755 (1898).
[17] Soc. pour l'ind. chim. à Bâle, French pat., 825,728, *C.A.*, **32**, 6667 (1938).
[18] Mills and Clark, *J. Chem. Soc.*, 175 (1936).
[19] Riesz, Berndt, and Hitschmann, *Monatsh.*, **50**, 328 (1928).

TABLE VI

DIALKYLBENZENE DERIVATIVES

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C. Amide	M.P., °C. Anilide and Reference
	A. o-Xylene Derivatives			
2,3-$(CH_3)_2C_6H_3$-	I[1]	47	167	....
2,3,4-$(CH_3)_2ClC_6H_2$-	I[2]	....	199	....
2,3,4-$(CH_3)_2BrC_6H_2$-	I[2]	63.5	195	....
3,4-$(CH_3)_2C_6H_3$-	I[2]	51–52	144	....
4,5,2-$(CH_3)ClC_6H_2$-	I[2]	....	207	....
4,5,2-$(CH_3)_2BrC_6H_2$-	I[6]	....	213	....
4,5,3-$(CH_3)_2BrC_3H_2$-	I[2]	85.5	191.5	....
3,4,2-$(CH_3)_2(O_2N)C_6H_2$-	I[2]	....	214	....
4,5,3-$(CH_3)_2(O_2N)C_6H_2$-	I[2]	69–70	180	....
4,5,2-$(CH_3)_2(O_2N)C_6H_2$-	I[2]	....	157–158	....

TABLE VI (*Continued*)

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C.	
			Amide	Anilide and Reference
	B. m-Xylene Derivatives			
2,6-$(CH_3)_2C_6H_3$-	I[7]	39	113	....
2,6,4-$(CH_3)_2ClC_6H_2$-	I[8]	56–58	191–192	....
2,6,3,5-$(CH_3)_2Cl_2C_6H$-	I[9]	....	>250	....
2,6,3-$(CH_3)_2BrC_6H_2$-	III[10]	....	161	....
2,6,3,5-$(CH_3)_2Br_2C_6H$-	I[10]	107	220	....
2,4-$(CH_3)_2C_6H_3$-	I,[11] III	34	138–139	....
2,4,5-$(CH_3)_2ClC_6H_2$-	I[12]	....	195	....
2,4,3,5-$(CH_3)_2Cl_2C_6H$-	I[9]	....	>300	....
2,4,5-$(CH_3)_2BrC_6H_2$-	I[13]	62–63	189–190	152[22]
2,4,3,5-$(CH_3)_2Br_2C_6H$-	II[14]	....	>300	....
2,4,5-$(CH_3)_2IC_6H_2$-	I[15]	73	176	153[15]
2,4,3,5-$(CH_3)_2I_2C_6H$-	I[15]	85–87	242–245 (dec.)	....
2,4,3-$(CH_3)_2(O_2N)C_6H_2$-	I[18]	96	172	....
2,4,6-$(CH_3)_2(O_2N)C_6H_2$-	I[18]	97	108	....
2,4,5-$(CH_3)_2(O_2N)C_6H_2$-	I[18, 19]	98	179	....
2,4,3,5-$(CH_3)_2(O_2N)_2C_6H$-	I[20, 21]	123	193	154[20]
2,4,5,6-$(CH_3)_2(O_2N)_2C_6H$-	I[18]	117–118	158	....
3,5-$(CH_3)_2C_6H_3$-	I[1, 23]	94	135	119[23]
3,5,2-$(CH_3)_2BrC_6H_2$-	I[29]	75	158	179[22]
	C. p-Xylene Derivatives			
2,5-$(CH_3)_2C_6H_3$-	I,[11] III[18]	24–26	147–148	....
2,5,4-$(CH_3)_2ClC_6H_2$-	II[42]	....	....	....
2,5,3,4-$(CH_3)_2Cl_2C_6H$-	I[45]	62	201	....
3,6,2,4-$(CH_3)_2Cl_2C_6H$-	I[45]	81	150	....
2,5,3,6-$(CH_3)_2Cl_2C_6H$-	I[45]	71	165	....
2,5,4-$(CH_3)_2BrC_6H_2$-	I[13c]	77–78	200–201	....
2,5,3,6-$(CH_3)_2Br_2C_6H$-	I[17]	78–79	198	....
3,6,2-$(CH_3)_2(O_2N)C_6H_2$-	III[34, 44]	109.5–110.5	191–192	182–183[24]
2,5,4-$(CH_3)_2(O_2N)C_6H_2$-	II[24]	74.5–75.5	197–198	131[24]
2,5,3-$(CH_3)_2(O_2N)C_6H_2$-	II,[24] III[44]	60–61	172–173	143–144[24]
	D. Methylalkylbenzene Derivatives			
2,5-$CH_3(C_2H_6)C_6H_3$-	I[25]	+3	71	....
5,2,4-$CH_3(C_2H_5)BrC_6H_2$-	I[25]	Oil	143	....
2,4-$CH_3(n\text{-}C_3H_7)C_6H_3$-	I[28]	175	....	....
2,5-$CH_3(n\text{-}C_3H_7)C_6H_3$-	I[27]	....	101–102	....
5,2-$CH_3(n\text{-}C_3H_7)C_6H_3$-	I[27]	....	112–113	....
3,4-$CH_3[(CH_3)_2CH]C_6H_3$-	I[28]	....	90	....
4,3-$CH_3[(CH_3)_2CH]C_6H_3$-	I[28]	....	105	....
4,2-$CH_3[(CH_3)_2CH]C_6H_3$-	I[29]	....	162	....
4,2,5-$CH_3[(CH_3)_2CH]BrC_6H_2$-	I[29]	....	170.5	....
2,4-$CH_3[(CH_3)_2CH]C_6H_3$-	I[30]	Liquid	75–75.5	....

TABLE VI (*Continued*)

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C. Amide	M.P., °C. Anilide and Reference
		D. Methylalkylbenzene Derivatives (*Continued*)		
2,4,5-$CH_3[(CH_3)_2CH]BrC_6H_2$-	I[31]	....	162	....
2,5-$CH_3[(CH_3)_2CH]C_6H_3$-	I,[32, 46] II[47]	....	115–116	....
5,2,4-$CH_3[(CH_3)_2CH]ClC_6H_2$-	I[36]	65	190	178[49]
5,2-$CH_3[(CH_3)_2CH]C_6H_3$-	I[45]	....	150	....
2,5,4-$CH_3[(CH_3)_2CH]ClC_6H_2$-	II[35, 37]	64	168	....
2,5,4-$CH_3[(CH_3)_2CH]BrC_6H_2$-	I[33]	....	152	....
2,5,3-$CH_3[(CH_3)_2CH](O_2N)C_6H_2$-	I[34]	....	138–139	....
2,4-$(CH_3)[(CH_3)_3C]C_6H_3$-	I[40]	....	94–95	....
2,5-$CH_3(sec\text{-}C_4H_9)C_6H_3$-	I[53]	B.p. 162–164 (12 mm.)	....	125[53]
2,5-$CH_3(C_4H_9)C_6H_3$-	I[40]	....	113	....
2,4-$(CH_3)(sec\text{-}C_4H_9)C_6H_3$-	I[53]	B.p. 164–165 (11 mm.)	....	121[53]
		E. Ethylalkylbenzene Derivatives		
3,4-$(C_2H_5)_2C_6H_3$-	I[38]	....	119	....
2,4-$(C_2H_5)_2C_6H_3$-	I[38]	....	101–102	....
2,5-$(C_2H_5)_2C_6H_3$-	I[38, 39]	....	97.5	....
2,5-$C_2H_5(n\text{-}C_3H_7)C_6H_3$-	I[41]	....	112–113	....
2,5-$C_2H_5(i\text{-}C_3H_7)C_6H_3$-	I[42]	B.p. 158 (10 mm.)	....	110[41, 42, 50]
		F. Disulfonyl Chlorides		
1,2-$(CH_3)_2C_6H_2$-3,5-	II	79	....	199[51]
1,3-$(CH_3)_2C_6H_2$-4,6-	I,[35] II[35, 43, 51]	128–131	248–249	....
1,3-$(CH_3)_2C_6H_2$-2,4-	I[35, 43]	Liquid	223–224	....
1,4-$(CH_3)_2C_6H_2$-2,5-	II[35b, 44]	164	310	223[51]
1,4-$(CH_3)_2C_6H_2$-2,6-	I,[48] II[35b, 44, 51]	81	297	174[51]
1,4-$(CH_3)_2C_6H_2$-2,3-	IH[43, 44]	....	142	....

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[1] Moschner, *Ber.*, **34**, 1261 (1901).

[2] Simonsen, *J. Chem. Soc.*, **103**, 1148 (1913).

[3] Krüger, *Ber.*, **18**, 1757 (1885).

[4] Stallard, *J. Chem. Soc.*, **89**, 809 (1906).

[5] Jacobsen, *Ber.*, **10**, 1012 (1877).

[6] Jacobsen, *Ber.*, **17**, 2374 (1884).

[7] Moody, *Chem. News*, **58**, 21 (1888).

[8] Klages, *Ber.*, **29**, 311 (1896).

[9] Koch, *Ber.*, **23**, 2319 (1890).

[10] Jacobsen and Weinberg, *Ber.*, **11**, 1535 (1878).

[11] Jacobsen, *Ber.*, **11**, 20 (1878); *Ann.*, **184**, 187 (1877).

[12] Jacobsen, *Ber.*, **18**, 1761 (1885).

[13] (*a*) Weinberg, *Ber.*, **11**, 1063 (1878). (*b*) Moody, *Chem. News*, **65**, 60 (1892). (*c*) Nölting and Kohn, *Ber.*, **19**, 139 (1886).

[14] Jacobsen, *Ber.*, **21**, 2825 (1888).

[15] Töhl and Bauch, *Ber.*, **26**, 1106 (1893).

[16] Töhl and Eberhard, *Ber.*, **26**, 2942 (1893); see also Iles and Remsen, *Ber.*, **11**, 229 (1878).

[17] Moody and Nicholson, *J. Chem. Soc.*, **57**, 977 (1890).

[18] Claus and Schmidt, *Ber.*, **19**, 1421 (1886).

[19] Chem. Fabr. von Heyden, German pat., 83,997, *Frdl.*, **4**, 39.

[20] Karslake and Morgan, *J. Am. Chem. Soc.*, **30**, 829 (1908).

[21] Limpricht and Gronow, *Ber.*, **18**, 2192 (1885).

[22] Junghahn, *Ber.*, **35**, 3755 (1902).

[23] Armstrong and Wilson, *Chem. News*, **83**, 46 (1901).

[24] Karslake and Huston, *J. Am. Chem. Soc.*, **36**, 1246–1254 (1914).

[25] Defren, *Ber.*, **28**, 2649 (1895).

[26] Claus and Stüsser, *Ber.*, **13**, 901 (1880).

[27] Widman, *Ber.*, **24**, 446 (1891).

[28] Sprinkmeyer, *Ber.*, **34**, 1954 (1901).

[29] Kelbe and Czarnowski, *Ann.*, **235**, 276 (1886); *Ber.*, **17**, 1747 (1884).

[30] Kelbe, *Ann.*, **210**, 34 (1881); Spica, *Gazz. chim. ital.*, **12**, 552 (1882).

[31] Kelbe and v. Czarnowski, *Ann.*, **235**, 276 (1886).

[32] Roderburg, *Ber.*, **6**, 669 (1873); Bechler, *J. prakt. Chem.*, [2] **8**, 168 (1873); Berger, *Ber.*, **10**, 97 (1877); Kelbe, *Ber.*, **19**, 1969 (1886).

[33] Kelbe and Koschnitzky, *Ber.*, **19**, 1731 (1886).

[34] Errera, *Gazz. chim. ital.*, **19**, 537 (1889).

[35] (*a*) Pollak and Meissner, *Monatsh.*, **50**, 237 (1928). (*b*) Pollak and Lustig, *Ann.*, **433**, 191 (1923).

[36] Jünger and Klages, *Ber.*, **29**, 315 (1896).

[37] Carrara, *Gazz. chim. ital.*, **19**, 170 (1889).

[38] Voswinkel, *Ber.*, **21**, 3500 (1888).

[39] Remsen and Noyes, *Am. Chem. J.*, **4**, 200 (1882).

[40] Kelbe and Baur, *Ber.*, **16**, 2560 (1883); *Baur*, *Ber.*, **24**, 2834 (1891).

[41] Widman, *Ber.*, **23**, 3085 (1890); **24**, 458 (1891).

[42] Klages and Keil, *Ber.*, **36**, 1641 (1903).

[43] Holleman, Choufoer, and Alozery, *Rec. trav. chim.*, **48**, 1075 (1929).

[44] Holleman, *Anales soc. españ. fís. quím.*, **27**, 473 (1929); *C.A.*, **24**, 85 (1930); see also Choufoer, *C.A.*, **19**, 2195 (1925).

[45] Wahl, *Compt. rend.*, **200**, 936 (1935).

[46] Kuan, *J. Chem. Soc. Japan*, **52**, 473 (1931); *C.A.*, **26**, 5081 (1932).

[47] Le Fèvre, *J. Chem. Soc.*, 1501 (1934).

[48] Pollak and Schadler, *Monatsh.*, **39**, 144 (1918).

[49] Klages and Kraith, *Ber.*, **32**, 2555 (1899).

[50] von der Becke, *Ber.*, **23**, 3194 (1890).

[51] Pollak, Heimberg-Krauss, Katscher, and Lustig, *Monatsh.*, **56**, 358 (1930).

[52] I. G. Farbenind. A.-G., British pat., 281,290, *C.A.*, **22**, 3417 (1928).

[53] Shoesmith and McGechen, *J. Chem. Soc.*, 2231 (1930).

TABLE VII

POLYALKYLBENZENE DERIVATIVES

Aryl Group of Sulfonyl Chloride	Reagent and Reference(s)	M.P., °C.	M.P. of Amide, °C
2,3,4-$(CH_3)_3C_6H_2$-	I[1]	....	195–196
2,3,6-$(CH_3)_3C_6H_2$-	I[3]	....	113 (impure?)
2,3,6,5-$(CH_3)_3FC_6H$-	I[3]	36–37	174
2,3,6,4-$(CH_3)_3BrC_6H$-	I[3]	....	158
2,3,6,4,5-$(CH_3)_3Br_2C_6$-	I[3]	....	250 (decomp.)
2,4,5-$(CH_3)_3C_6H_2$-	I[3]	61–62	181
2,4,5,3-$(CH_3)_3BrC_6H$-	I[3]	....	187–188
2,3,5-$(CH_3)_3C_6H_2$-	I[2, 4a]	....	178–179
2,3,5,4-$(CH_3)_3BrC_6H$-	I[4b]	....	194.5
2,3,5,6-$(CH_3)_3BrC_6H$-	I[2, 4a]	....	183–184
2,3,6,5,4-$(CH_3)_3FClC_6$-	I[5]	....	171
2,3,6,5,4-$(CH_3)_3FBrC_6$-	I[5]	....	149
2,4,6-$(CH_3)_3C_6H_2$-	I[2, 6, 7, 8]	57	141–142
2,4,6,3-$(CH_3)_3IC_6H$-	I[3]	....	156

TABLE VII (*Continued*)

Aryl Group of Sulfonyl Chloride	Reagent and Reference(s)	M.P., °C.	M.P. of Amide, °C
4,5,2-$(CH_3)_2(C_2H_5)C_6H_2$-	I[1]	....	126
3,6,2-$(CH_3)_2(C_2H_5)C_6H_2$-	I[1]	....	117
2,4,5-$(CH_3)_2(C_2H_5)C_6H_2$-	I[1]	....	148
2,6,4-$(CH_3)_2(C_2H_5)C_6H_2$-	I[10]	....	128
2,6,4,3-$(CH_3)_2(C_2H_5)BrC_6H$-	I[10]	....	156
2,4,6-$(CH_3)_2(C_2H_5)C_6H_2$-	I[10]	....	116–117
2,3,4,5-$(CH_3)_4C_6H$-	I[4a]	....	187
2,3,4,6-$(CH_3)_4C_6H$-	I[4a, 11]	....	118
2,3,5,6-$(CH_3)_4C_6H$-	I[12]	99	155
2,3,5,6,4-$(CH_3)_4ClC_6$-	I[13]	53–54	180–181
1,3,5-$(CH_3)_3C_6H$-2,4-di-	II[14, 15, 16]	125	244
1,3,5,6-$(CH_3)_3(O_2N)C_6$-2,4-di-	III[14]	198–199.5	....

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[1] Jacobsen, *Ber.*, **19**, 2517 (1886).

[2] Jacobsen, *Ber.*, **19**, 1223 (1886).

[3] (*a*) Schreinemakers, *Rec. trav. chim.*, **16**, 418 (1897). (*b*) Radloff, *Ber.*, **11**, 32 (1878). (*c*) Anschütz, *Ann.*, **235**, 184 (1886).

[4] (*a*) Kelbe and Patbe, *Ber.*, **19**, 1551 (1886). (*b*) Jacobsen, *Ber.*, **22**, 1585 (1889).

[5] Töhl and Müller, *Ber.*, **26**, 1110 (1893).

[6] Holtmeyer, *Z. Chem.*, 686 (1867).

[7] Hall and Remsen, *Ber.*, **10**, 1040 (1877).

[8] Jacobsen, *Ann.*, **184**, 185 (1877).

[9] Töhl and Eckel, *Ber.*, **26**, 1102 (1893).

[10] Töhl and Geyger, *Ber.*, **25**, 1538 (1892).

[11] Jacobsen, *Ber.*, **15**, 1854 (1882).

[12] Jacobsen and Schnapauff, *Ber.*, **18**, 2843 (1885).

[13] Töhl, *Ber.*, **25**, 2760 (1892).

[14] Holleman, *Anales soc. españ. fís. quím.*, **27**, 473 (1929); Holleman, Choufoer, and Alozery, *Rec. trav. chim.*, **48**, 1075 (1929).

[15] Backer, *ibid.*, **54**, 544 (1935).

[16] Steinkopf *et al.*, *J. prakt. Chem.*, [2] **117**, 1 (1927).

TABLE VIII

PHENOL DERIVATIVES

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C.	
			Amide	Anilide and Reference
		Monosulfonyl Chlorides		
2-$CH_3OC_6H_4$-	I[1, 2, 5]	55–56	169–171	161[58]
2-$C_2H_5OC_6H_4$-	I[2, 3, 4]	65–66	156–163	158[59]
2-$CH_3COOC_6H_4$-	I[48]	73–74	....	106–107[48]
2-HOC_6H_4-	....	....	....	123[62]
3-HOC_6H_4-	I[51]	Oil	....	....
3-$CH_3OC_6H_4$-	I[7, 8, 50]	(B.p. 156–160 [20])	128	....
3-$C_2H_5OC_6H_4$-	I[6, 7]	38	128–131	88[10]
3-*n*-$C_3H_7OC_6H_4$-	I[7]	....	122	....
3-$C_2H_5OCO_2C_6H_4$-	I[49]	30–31	....	89–90[49]

TABLE VIII (*Continued*)

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C. Amide	M.P., °C. Anilide and Reference
		Monosulfonyl Chlorides (*Continued*)		
4-$CH_3OC_6H_4$-	I,[4, 5, 9, 52] II[64]	42–43	110–111; 113–116	110–111[66]
4-$C_2H_5OC_6H_4$-	I,[8, 9, 10] II[64]	37–39	149–150	84[10]
4-*n*-$C_3H_7OC_6H_4$-	II[64]	....	116–117	....
4-*n*-$C_4H_9OC_6H_4$-	II[64]	....	103–104	....
4-$CH_3COOC_6H_4$-	I[53]	78	....	126–127[53]
4-$C_6H_5COOC_6H_4$-	I[11]	115–116	234–236	....
4-$C_2H_5OCO_2C_6H_4$-	I[54]	75	....	102[49]
5,2-$F(CH_3O)C_6H_3$-	II[64]	....	174–175	....
5,2-$Cl(CH_3O)C_6H_3$-	I, II[44, 64]	104	154; 150–151	....
5,2-$Br(CH_3O)C_6H_3$-	II[64]	....	147–148	....
5,2-$Cl(C_2H_5O)C_6H_3$-	II[64]	....	134–134.5	....
5,2-$Br(C_2H_6O)C_6H_3$-	II[64]	....	144–144.5	....
3,4-$Cl(CH_3O)C_6H_3$-	I,[70] II[64,]	81–82	130–131	....
3,4-$Br(CH_3O)C_6H_3$-	II[64]	....	139–140	....
3,4-$Cl(C_2II_6O)C_6H_3$-	II[64]	....	132–133	....
3,4-$Br(C_2H_5O)C_6H_3$-	II[64]	....	134–135	....
3,5,4-$Br_2(HO)C_6H_2$-	I[12, 13, 14]	127–128	....	177[69]
3,5,4-$(O_2N)_2(HO)C_6H_2$-	I[60]	....	....	177[60]
2,4,6,3-$Br_3(CH_3O)C_6H$-	I[71]	57.2–58.2	176.6–178	160[71]
2,4,6,3-$(O_2N)_3(HO)C_6H$-	III[65]	161–162	....	....
3,4-$(O_2N)(CH_3O)C_6H_3$-	I,[15] III[15]	66	146	....
4,2-$CH_3(HO)C_6H_3$-	I[18]	Oil	....	....
4,2-$CH_3(CH_3O)C_6H_3$-	I[46]	79	167–168	142[46]
3,2-$CH_3(CH_3O)C_6H_3$-	I[73]	Oil	143–144	....
4,3-$CH_3(CH_3O)C_6H_3$-	I[17]	Solid (oil?)	123	....
4,3-$CH_3(C_2H_5O)C_6H_3$-	I[16]	"Tables"	137	....
2,3-$CH_3(CH_3O)C_6H_3$-	I[78]	Oil	164	....
2,6-$CH_3(CH_3O)C_6H_3$-	I[46]	51–52	127–128	131–132[46]
3,5-$CH_3(CH_3O)C_6H_3$-	I[46]	47–48	118–119	....
3,4-$CH_3(CH_3O)C_6H_3$-	II[64]	....	137	....
3,4-$CH_3(C_2H_6O)C_6H_3$-	II[64]	....	148–149	....
3,4-$CH_3(n\text{-}C_4H_9O)C_6H_3$-	II[64]	....	95–96	....
2,4-$CH_3(CH_3O)C_6H_3$-	I,[46, 74] H,[64] III[46]	23	129–130	104[46]
2,4-$CH_3(C_2H_6O)C_6H_3$-	II[64]	....	110–111	....
2,4-*n*-$C_3H_7(C_2H_6O)C_6H_3$-	I[27]	....	84	....
2,4-$CH_3(C_2H_6OCO_2)C_6H_3$-	II[43]	Oil	....	149[48]
3,5,4-$CH_3(Br)(HO)C_6H_2$-	I[66]	94	....	165–166[55]
3,5,4-$CH_3(Br)(CH_3COO)C_6H_2$-	I[55]	131	....	....
2,5-$CH_3(CH_3O)C_6H_3$-	I[20, 21]	Oil	150–151	....
2,5-$CH_3(C_2H_6O)C_6H_3$-	I[21, 22, 23]	Oil	143–144	....
5,2-$CH_3(CH_3O)C_6H_3$-	I,[24, 25, 26] II[47, 64]	83–84	180–181,182	....

TABLE VIII (*Continued*)

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C.	
			Amide	Anilide and Reference
		Monosulfonyl Chlorides (Continued)		
5,2-$CH_3(C_2H_5O)C_6H_3$-	I,[24] II[64]	....	138–139	....
5,2-$CH_3(n\text{-}C_3H_7O)C_6H_3$-	II[64]	....	126–127	....
5,2-$CH_3(CH_3COO)C_6H_3$-	I[45]	55–56	....	....
5,2-$CH_3(C_2H_5OCO_2)C_6H_3$-	I[56]	....	....	126[56]
5,2-$n\text{-}C_3H_7(CH_3O)C_6H_3$-	I[28]	Oil	133	....
5,2-$n\text{-}C_3H_7(C_2H_5O)C_6H_3$-	I[27]	....	97–98	....
5,2-$t\text{-}C_4H_9(CH_3COO)C_6H_3$	I[48]	103	....	....
5,2-$t\text{-}C_5H_{11}(CH_3COO)C_6H_3$-	I[48]	(B.p. 142–146 [14])	....	....
5,3,2-$CH_3(Br)(OH)C_6H_2$-	I,[57] II[57]	94–95	....	....
5,3,2-$CH_3(Br)(CH_3COO)C_6H_2$-	III[57]	84–85	....	....
5,3,2-$CH_3(O_2N)(HO)C_6H_2$-	I[72]	86–87	205–210	217
5,3,2-$CH_3(O_2N)(CH_3COO)C_6H_2$-	I[72]	101.5	....	141.5
3,4-$(CH_3O)_2C_6H_3$-	I,[35, 38] II[63, 64]	76	136–137	131–132[61]
4,3-$C_2H_5O(CH_3O)C_6H_3$-	I[35]	72	192	....
3,4-$C_2H_5O(CH_3O)C_6H_3$-	I[35]	102–103	166	....
3,4-$(C_2H_5O)_2C_6H_3$-	II[64]	....	162–163	....
2,4-$(CH_3O)_2C_6H_3$-	I,[69] II[64]	70.5	166–167	....
2,4-$(C_2H_5O)_2C_6H_3$-	II[64]	....	184–185	....
2,5-$(CH_3O)_2C_6H_3$-	II[64]	....	148	....
2,5-$(C_2H_5O)_2C_6H_3$-	II[64]	....	154–155	....
3,5-$(C_6H_5COO)_2C_6H_3$-	I[65]	105	....	....
2,3,4-$(CH_3O)_3C_6H_2$-	II[64]	....	123–124	....
2,3,5-$(CH_3O)_3C_6H_2$-	I[67]	98	....	....
2,4,5-$(CH_3O)_3C_6H_2$-	I[67]	130	76	170
4,5,2-$(CH_3O)_2(O_2N)C_6H_2$-	III[63]	128	132	....
4,5,2-$(CH_3O)_2(NO)C_6H_2$-	I[68]	132	198–201	....
2,4,5-$CH_3(CH_3O)_2C_6H_2$-	I[63, 76]	75	191	....
2,4,5,6-$CH_3(CH_3O)_2(O_2N)C_6H$-	III[76]	141	....	....
3,5,2-$(CH_3)_2(HO)C_6H_2$-	II[39]	93	....	....
		Di and Trisulfonyl Chlorides		
1-HOC_6H_3-2,4-	II[29, 30, 37]	89	....	205[37]
1,2-$HO(CH_3)C_6H_2$-4,6-	II[31, 37, 40]	85–86	....	154[37, 40]
1-$CH_3OC_6H_3$-2,4-	I,[5, 32] II[45]	86	239–240	209
1-$C_2H_5OC_6H_3$-2,5-	I[33]	106–108	233	....
1-$C_2H_5OC_6H_3$-2,4-	II[45]	104–107	....	....
1-$CH_3COOC_6H_3$-2,4-	III[46]	91	....	....
1,3-$CH_3(HO)C_6H_2$-4,6-	I,[34] II[30, 37, 40]	84–89	....	185[37, 40]
1,3-$CH_3(HO)C_6H$-2,4,6-	II[29]	151	....	....
1,3-$CH_3(CH_3O)C_6H_2$-4,6-	I[46]	111–112	259–260	....
1,3-$CH_3(CH_3COO)C_6H_2$-4,6-	III[45]	109	....	....
1,2,3-$CH_3(O_2N)(HO)C_6H$-4,6-	III[40]	183	....	212–215
1,2,3-$CH_3(CH_3O)(O_2N)C_6H$-4,6-	I[46]	147–148	235	....

TABLE VIII (*Continued*)

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	Amide	M.P., °C. Anilide and Reference
Di and Trisulfonyl Chlorides (*Continued*)				
1,4-$CH_3(OH)C_6H_2$-3,5-	I,^{72} II$^{30, 37, 40, 75}$	105	....	231?^{72}, 129$^{37, 40}$
1,4-$CH_3(CH_3COO)C_6H_2$-3,5-	I,$^{40, 42}$ III^{72}	115–121	....	105–110^{40}
1,2,3-$HO(CH_3)_2C_6H$-4,6-	II^{39}	104–105	....	232^{39}
1,3,4-$HO(CH_3)_2C_6H$-2,5-	II^{39}	72	....	160^{39}
1,2,5-$HO(CH_3)_2C_6H$-3,6-	II^{39}	58	....	173^{39}
1,3,5-$HO(CH_3)_2C_6H$-2,4-	II^{39}	89–91	....	160–161^{39}
1,3,5-$HO(CH_3)_2C_6H$-2,6-(?)	II^{39}	117–119	....	205–207^{39}
1,2-$HOC_6H_2(COOH)$-4,6-	II^{31}	185	....	....
1-HOC_6H_2-2,4,6-	II$^{30, 37}$	193	....	247^{37}
1,3-$CH_3(OH)C_6H$-2,4,6-	II$^{29, 30, 37}$	151	....	290 (dec.)
1,2-$(HO)_2C_6H_2$-3,5-	II^{31}	149–150	....	....
1,2-$O_2SO_2C_6H_2$-3,5-	II^{31}	143	....	304^{31}
1,3-$(HO)_2C_6H_2$-4,6-	II^{38}	178–179	....	>300
1,3-$(HO)_2C_6H$-2,4,6-	II^{38}	168	....	243^{38}
1,4-$(HO)_2C_6H_2$-2,6-	II^{41}	113–114	....	170–171^{41}
1,3,5-$(HO)_3C_6H$-2,4-	II$^{28, 42}$	184	....	295 (dec.)^{42}
1,2,3-$(HO)_3C_6H$-4,6-	II^{42}	178 (dec.)	....	....

[1] Haitinger, *Monatsh.*, **4**, 174 (1883).
[2] Franklin, *Am. Chem. J.*, **20**, 461 (1898).
[3] Moody, *Chem. News*, **67**, 35 (1893).
[4] Gattermann, *Ber.*, **32**, 1154 (1899).
[5] Shober, *Am. Chem. J.*, **18**, 860 (1896).
[6] Delisle and Lagai, *Ber.*, **23**, 3393 (1890).
[7] Shober and Kiefer, *Am. Chem. J.*, **17**, 458 (1895).
[8] Shober and Bowers, *ibid.*, **25**, 72 (1901).
[9] Moody, *Chem. News*, **66**, 247 (1892).
[10] Lagai, *Ber.*, **25**, 1838 (1892).
[11] Schreinemakers, *Rec. trav. chim.*, **16**, 422 (1897).
[12] Zincke and Glahn, *Ber.*, **40**, 3042 (1907).
[13] Anschütz, *Ann.*, **358**, 95 (1908).
[14] Zincke and Brune, *Ber.*, **41**, 902 (1908).
[15] Gnehm and Knecht, *J. prakt. Chem.*, [2] **74**, 95 (1906).
[16] Graesser-Thomas, Gulland, and Robinson, *J. Chem. Soc.*, 1971 (1926).
[17] Bromwell, *Am. Chem. J.*, **19**, 572 (1897).
[18] Hayduck, *Ann.*, **172**, 216 (1874).
[19] Claus and Krauss, *Ber.*, **20**, 3091 (1887).
[20] Parks, *Am. Chem. J.*, **15**, 328 (1893).
[21] Limpricht and Heffter, *Ann.*, **221**, 355 (1883).
[22] Dashiell, *Am. Chem. J.*, **15**, 129 (1893).
[23] Remsen and Palmer, *ibid.*, **8**, 245 (1886).
[24] Metcalf, *ibid.*, **15**, 306–311 (1893).
[25] Alleman, *ibid.*, **31**, 36 (1904).
[26] Smiles and Le Rossignol, *J. Chem. Soc.*, **93**, 758 (1908).
[27] Klages, *Ber.*, **37**, 3990 (1904).
[28] Klages, *Ber.*, **32**, 1439 (1899).
[29] Gebauer-Fülnegg and Riesz, Austrian pat., 119,960, *C.A.*, **25**, 1262 (1931).
[30] Riess, Berndt, and Hitschmann, *Monatsh.*, **50**, 328 (1928).
[31] Pollak and Gebauer-Fülnegg, *ibid.*, **47**, 109 (1926).

[32] Shober, *Am. Chem. J.*, **15**, 388 (1893).
[33] Zander, *Ann.*, 198, 28 (1879).
[34] Claus and Krauss, *Ber.*, **20**, 3094 (1887).
[35] Paul, *Ber.*, **29**, 2778 (1905).
[36] Gaspari, *Gazz. chim. ital.*, **26**, II, 234 (1896).
[37] Pollak, Gebauer-Fülnegg, and Riesz, *Monatsh.*, **46**, 383 (1926).
[38] Pollak, Gebauer-Fülnegg, and Blumenstock, *ibid.*, **46**, 499 (1926).
[39] Katscher, Lehr, Harnisch, and Steinhardt, *ibid.*, **56**, 381 (1930).
[40] Riess and Pilpel, *ibid.*, **50**, 335 (1928).
[41] Litvay, Riesz, and Landau, *Ber.*, **62B**, 1863 (1929).
[42] Pollak, Gebauer-Fülnegg, Weinmayr, and Litvay, *Monatsh.*, **47**, 537 (1927).
[43] Gebauer-Fülnegg and Schlesinger, *Ber.*, 61B, 781 (1928).
[44] Gauntlett and Smiles, *J. Chem. Soc.*, **127**, 2745 (1925).
[45] Gebauer-Fülnegg and Meissner, *Monatsh.*, **50**, 55 (1928).
[46] Haworth and Lapworth, *J. Chem. Soc.*, **123**, 2982 (1923).
[47] Stewart, *ibid.*, **121**, 2555 (1922).
[48] Anschütz, *Ann.*, **415**, 69 (1918).
[49] Zincke and Ebel, *Ber.*, **47**, 926 (1914).
[50] Fries and Engelbertz, *Ann.*, **407**, 210 (1915).
[51] Szathmáry, *Ber.*, **43**, 2486 (1910).
[52] Fichter and Tamm, *Ber.*, **43**, 3036 (1910).
[53] Anschütz and Molineus, *Ann.*, **415**, 56 (1918).
[54] Zincke and Ebel, *Ber.*, **47**, 1103 (1914)
[55] Zincke and Brune, *Ber.*, **44**, 187 (1911).
[56] Zincke and Arnold, *Ber.*, **50**, 119 (1917).
[57] Zincke and Kempf, *Ber.*, **44**, 418 (1911).
[58] Gattermann, *Ber.*, **32**, 1154 (1899).
[59] Zincke and Brune, *Ber.*, **41**, 905 (1908).
[60] Ullmann, *Ann.*, **366**, 108 (1909).
[61] Gaspari, *Gazz. chim. ital.*, **26**, II, 235 (1896).
[62] Ullmann and Gross, *Ber.*, **43**, 2701 (1910).
[63] Brown and Robinson, *J. Chem. Soc.*, **111**, 952 (1917).
[64] Huntress and Carten, *J. Am. Chem. Soc.*, **62**, 603 (1940).
[65] Suter and Harrington, *ibid.*, **59**, 2575 (1937).
[66] Bennett and Youle, *J. Chem. Soc.*, 887 (1938).
[67] Dorn, Warren, and Bullock, *J. Am. Chem. Soc.*, **61**, 144 (1939).
[68] Zika, *Collection Czechoslov. Chem. Communications*, **6**, 60 (1934).
[69] Suter and Hansen, *J. Am. Chem. Soc.*, **55**, 2080 (1933).
[70] Child, *J. Chem. Soc.*, 715 (1932).
[71] Lauer and Langkammerer, *J. Am. Chem. Soc.*, **56**, 1628 (1934).
[72] Anschütz and Curtin, *Ann.*, **467**, 256 (1927).
[73] Shah, Bhatt, and Kanga, *J. Chem. Soc.*, 1375 (1933).
[74] Suter and McKenzie, *J. Am. Chem. Soc.*, **56**, 2470 (1934).
[75] Gibson and Smiles, *J. Chem. Soc.*, **123**, 2388 (1923).
[76] Graesser-Thomas, Gulland, and Robinson, *ibid.*, 1971 (1926).

TABLE IX

SULFONYL CHLORIDES OF AROMATIC AMINES AND DERIVATIVES

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C. Amide	M.P., °C. Anilide and Reference
4-$CH_3CONHC_6H_4$-	I,[1] II[3, 15]	149	219	214[15]
4-$ClCH_2CONHC_6H_4$-	II[10]	112	216	187[10]
4-$C_2H_5CONHC_6H_4$-	II[11]	113	226.5–227.5	....
4-*n*-$C_3H_7CONHC_6H_4$-	H[11]	120–121	236–237	....
4-*iso*-$C_3H_7CONHC_6H_4$-	II[11]	131–132	248–249	....
4-*n*-$C_4H_9CONHC_3H_4$-	II[11]	115–116	209–210	....
4-*iso*-$C_4H_9CONHC_6H_4$-	II[11]	120–121	....	....

TABLE IX (*Continued*)

			M.P., °C.	
Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	Amide	Anilide and Reference
4-$C_6H_5CONHC_6H_4$-	I^{1}	176	....	....
4-$C_6H_5SO_2NHC_6H_4$-	I^{1}	177	....	....
4-$C_2H_5OCONHC_6H_4$-	II^{11}	103	241–242	....
4-$CH_3CONHCONHC_6H_4$-	II^{23}	192–193	246–247	....
4-$(CH_2CO)_2NC_6H_4$-	II^{12}	....	234–238	....
4-$CH_3CO(CH_3)NC_6H_4$-	II^{11}	136–137	....	....
4-$CH_3CO(C_2H_5)NC_6H_4$-	II^{11}	142–143	....	....
3-$(CH_3)_2NC_6H_4$-	II^{9}	38	....	....
4-$(CH_3)_2NC_6H_4$-	II^{9}	108–111	....	....
2,5-$Cl(H_2N)C_6H_3$-	II^{7}	....	....	....
5,2-$O_2N(H_2N)C_6H_3$-	I^{17}	....	....	....
3,4-$O_2N(H_2N)C_6H_3$-	I$^{4, 5, 6}$	?	?	....
3,4-$O_2N(CH_3CONH)C_6H_3$-	III^{13}	104	186	....
4,3-$(CH_3O)(CH_3CONH)C_6H_3$-	II$^{11, 16, 22}$	149–152	226	....
4,3-$(C_2H_5O)(CH_3CONH)C_6H_3$-	II^{22}	129	....	....
2,5-$(C_2H_5O)(CH_3CONH)C_6H_3$-	II^{3}	133	....	182–183^{3}
4,3-$(CH_3O)(C_2H_5OCONH)C_6H_3$-	II^{22}	124	....	....
2,3,5-$(CH_3O)(O_2N)(CH_3CONH)C_6H_2$-	III^{21}	136	....	....
2,4,5-$(CH_3O)(O_2N)(CH_3CONH)C_6H_2$-	III$^{14, 21}$	152	....	....
4,3,5-$(CH_3O)(O_2N)(CH_3CONH)C_6H_2$-	III^{21}	105	....	....
4,6,3-$(CH_3O)(O_2N)(CH_3CONH)C_6H_2$-	III$^{14, 21}$	175	....	....
4,6,3-$(C_2H_5O)(O_2N)(CH_3CONH)C_6H_2$-	III$^{14, 21}$	132	....	....
4,6,3-$(CH_3O)(O_2N)(C_6H_5CONH)C_6H_2$-	III^{14}	220	....	....
4,6,3-$(CH_3O)(O_2N)(3\text{-}O_2NC_6H_4CONH)C_6H_2$-	III^{21}	178	....	....
4,6,3-$(C_2H_5O)(O_2N)(3\text{-}O_2NC_6H_4CONH)C_6H_2$-	III^{21}	162	....	....
2,4,5-$(CH_3O)_2(CH_3CONH)C_6H_2$-	II^{22}	175	....	....
2,5-$(CH_3)(CH_3CONH)C_6H_3$-	II^{2}	....	....	....
2,4-$(CH_3)(CH_3CONH)C_6H_3$-	H^{15}	98	202	....
2,4-$(CH_3)(CH_3CONHCONH)C_6H_3$-	II^{23}	199–201	226–227	....
5,2-$(CH_3)(CH_3CONH)C_6H_3$-	II$^{10, 15}$	125	242	....
4,3-$(CH_3)(CH_3CONH)C_6H_3$-	II$^{15, 22}$	142; 144	228	....
5,2-$(CH_3)(ClCH_2CONH)C_6H_3$-	II^{10}	87	231	....
3,4-$(CH_3)(CH_3CONH)C_6H_3$-	I^{19}	159	....	....
3,4-$(CH_3)(CH_3CONHCONH)C_6H_3$-	II^{23}	197–199	231–233	....
4,3-$(CH_3)(CH_3NH)C_6H_3$-	II^{9}	99–100	....	....
4,2,5-$(CH_3)(Cl)(CH_3CONH)C_6H_2$-	II^{22}	137	....	....
4,2,5-$(CH_3)(CH_3O)(CH_3CONH)C_6H_2$-	II^{22}	155	....	....
2,3,5-$(CH_3)(O_2N)(H_2N)C_6H_2$-	I^{20}	>260	230	....
4,6,3-$(CH_3)(O_2N)(CH_3CONH)C_6H_2$-	III^{21}	158	....	....
4,6,3-$(CH_3)(O_2N)(3\text{-}O_2NC_6H_4CONH)C_6H_2$-	III$^{14, 21}$	195	....	....
2,5,3,4-$(CH_3)(CH_3O)(O_2N)(CH_3CONH)C_6H$-	II^{21}	175	....	....

TABLE IX (*Continued*)

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C. Amide	M.P., °C. Anilide and Reference
2,5,4-$(CH_3)_2(CH_3CONH)C_6H_2$-	II[3]	160	....	....
2,4,5-$(CH_3)_2(CH_3CONH)C_6H_2$-	II[22]	147	....	....
2,5,3,4-$(CH_3)_2(O_2N)(CH_3CONH)C_6H$-	III[21]	178	....	....
2,4,6,3-$(CH_3)_2(O_2N)(CH_3CONH)C_6H$-	III[14, 21]	187	255	....
Di and Trisulfonyl Chlorides				
1,4-$(CH_3)(H_2N)C_6H_2$-3,5-	II[3, 10]	156	257	192[8]
1,4-$(CH_3)(CH_3CONH)C_6H_2$-2,5-	III[18]	125	....	....
1,4-$(CH_3)(ClCH_2CONH)C_6H_2$-2,5-	III[18]	118–119	....	....
1,2-$(CH_3)(H_2N)C_6H_2$-3,5-	II[10]	153	....	....
1,3-$(H_2N)_2C_6H_2$-4,6-	II[8]	274–275	187	236[8]
1-$H_2NC_6H_2$-2,4,6-	II[8]	175	291	240[8]

[1] (*a*) Schroeter, *Ber.*, **39**, 1563 (1906). (*b*) Gelmo, *J. prakt. Chem.*, [2] **77**, 369 (1908). (*c*) Pence and Winter, *J. Am. Chem. Soc.*, 61, 2977 (1939).

[2] Stewart, *J. Chem. Soc.*, **121**, 2556 (1922).

[3] Johnson and Smiles, *ibid.*, **123**, 2384 (1923).

[4] Fischer, *Ber.*, **24**, 3798 (1891).

[5] Goslich, *Ann.*, **180**, 103 (1875).

[6] Holleman, *Rec. trav. chim.*, **24**, 31 (1905).

[7] I. G. Farbenind. A.-G., French pat., 690,112, *C.A.*, **25**, 973 (1931).

[8] Lustig and Katscher, *Monatsh.*, **48**, 87 (1927).

[9] Schweitzer and Burr, German pat., 532,399, *C.A.*, **26**, 3262 (1932); U. S. pat., 1,939,025, *C.A.*, **28**, 1362 (1934).

[10] Jacobs and Heidelberger, *J. Am. Chem. Soc.*, **39**, 2429 (1917); Pollak, Pollak, Riesz, and Wittels *Monatsh.*, **58**, 118 (1931).

[11] Adams, Long, and Johanson, *J. Am. Chem. Soc.*, **61**, 2342 (1939).

[12] Adams, Long, and Jeanes, *ibid.*, **61**, 2346 (1939).

[13] Kermack, Spragg, and Tebrich, *J. Chem. Soc.*, 608 (1939).

[14] Comp. nat. de mat. col., German pat., 646,639, *C.A.*, **31**, 6899 (1937).

[15] Goldyrev and Postovskii, *J. Applied Chem.* (*U.S.S.R.*), **11**, 316 (1938).

[16] Child, *J. Chem. Soc.*, 715 (1932).

[17] Soc. pour l'ind à Bâle, Swiss pat., 162,735, *C.A.*, **28**, 2730 (1934).

[18] Riess, Pollak, and Wittels, *Ann.*, **487**, 264 (1931).

[19] Child and Smiles, *J. Chem. Soc.*, 2696 (1926).

[20] Hirwe and Jambhekar, *J. Indian Chem. Soc.*, **11**, 239 (1934).

[21] Comp. nat. de mat. col., French pat., 755,667, *C.A.*, **28**, 2196 (1934); French pat., 782,126, *C.A.*, **29**, 7092 (1935).

[22] I. G. Farbenind. A.-G., French pat., 742,361, *C.A.*, **27**, 3619 (1933).

[23] Cox, *J. Am. Chem. Soc.*, **62**, 744 (1940).

TABLE X

DERIVATIVES OF CARBOXYLIC ACIDS

Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C. Amide	M.P., °C. Anilide and Reference
1,2-$C_6H_4(COOCH_3)SO_2Cl$	III[1, 2]	63	....	....
1,2-$C_6H_4(COOC_6H_5)SO_2Cl$	III[3a, 4]	103–104	....	....
1,2-$C_6H_4(COOC_6H_4CH_3$-*o*$)SO_2Cl$	III[3]	112	....	....
1,2-$C_6H_4(COCl)SO_2Cl$	I[3b, 4–10]	40	....	194–195[4a, 6, 8, 45–47]

TABLE X (*Continued*)

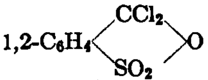
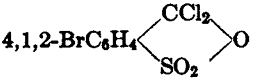
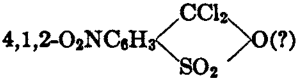
Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C.	
			Amide	Anilide and Reference
 $1,2\text{-}C_6H_4\begin{matrix}CCl_2\\SO_2\end{matrix}O$	$I^{3a,\ 5-11}$	79	....	....
$1,2\text{-}C_6H_4(CN)SO_2Cl$	$I^{3a,\ 12-17}$	68–70	160	$150–152^{18}$
$4,1,2\text{-}BrC_6H_4(COCl)SO_2Cl$	I^{18}	89–90	....	$238–239^{18}$
 $4,1,2\text{-}BrC_6H_4\begin{matrix}CCl_2\\SO_2\end{matrix}O$	I^{18}	99–100	....	....
$4,2,1\text{-}BrC_6H_3(CN)SO_2Cl$	I^{18}	82 or 90	>250	....
$4,2,1\text{-}O_2NC_6H_3(COOCH_3)SO_2Cl$	III^{19-21}	82 or 90	....	....
$4,2,1\text{-}O_2NC_6H_3(COOC_2H_5)SO_2Cl$	III^{19-21}	67–68	....	....
$4,2,1\text{-}O_2NC_6H_3(COOC_3H_7\text{-}n)SO_2Cl$	III^{18}	76	....	....
$4,2,1\text{-}O_2NC_6H_3(COOC_6H_5)SO_2Cl$	III^{19}	145–147	....	....
$4,2,1\text{-}O_2NC_6H_3(COOC_6H_4CH_3\text{-}o)\text{-}SO_2Cl$	III^{19}	150	....	....
$4,2,1\text{-}O_2NC_6H_3(COOC_6H_4CH_3\text{-}p)\text{-}SO_2Cl$	III^{19}	152	....	....
$4,2,1\text{-}O_2NC_6H_3(COCl)SO_2Cl(?)$	I^{21-23}	94–98	....	222^{21}
 $4,1,2\text{-}O_2NC_6H_3\begin{matrix}CCl_2\\SO_2\end{matrix}O(?)$	$I^{5,\ 22,\ 23}$	56–57	....	....
$4,2,1\text{-}O_2NC_6H_3(CN)SO_2Cl$	I^{22}	107–108	>270	$207–208^{22}$
$1,3\text{-}C_6H_4(COOH)SO_2Cl$	$I^{24,\ 26}$	133–134	233	....
$1,3\text{-}C_6H_4(COOCH_3)SO_2Cl$	III^{25}	63–65	....	....
$1,3\text{-}C_6H_4(COCl)SO_2Cl$	$I^{25,\ 26}$	Oil	170 (diamide)	$...^{26}$
$4,1,3\text{-}ClC_6H_3(COCl)SO_2Cl$	I^{27}	42–43	233	$219–220^{27}$
$4,1,3\text{-}BrC_6H_3(COOH)SO_2Cl?$	I^{28}	197	229–230	....
$5,1,3(?)\text{-}ClC_6H_3(COCl)SO_2Cl$	I^{31}	....	Solid	....
$5,1,3\text{-}BrC_6H_3(COCl)SO_2Cl$	I^{28}	Liquid	....	....
$1,4\text{-}HOOCC_6H_4SO_2Cl$	....	....	....	$252–253^{30}$
$1,4\text{-}NCC_6H_4SO_2Cl$	I^{30}	111–112	168–169	112^{30}
$2,1,4\text{-}O_2NC_6H_3(COCl)SO_2Cl$	I^{44}	160	226	....
$2,1,4\text{-}O_2NC_6H_3(COOH)SO_2Cl$	I^{44}	202	192	....
$1,3,5\text{-}C_6H_3(COCl)(SO_2Cl)_2$	I^{28}	86–87	290	....
$1,3,5\text{-}C_6H_3(COOH)(SO_2Cl)_2$	$II,^{50}\ III^{32}$	183, 193	....	....
$2,5,4,1\text{-}CH_3(O_2N)C_6H_2(COCl)\text{-}SO_2Cl$	I^{28}	90	273–294	245^{28}
$4,5,2,1\text{-}CH_3(O_2N)C_6H_2(COCl)\text{-}SO_2Cl$	I^{34}	93 or 133	....	195^{48}
$5,2,1\text{-}CH_3C_6H_3(COCl)SO_2Cl$	I^{28}	59	....	....
$5,2,1\text{-}CH_3C_6H_3(CN)SO_2Cl$	I^{30}	67	....	....
$2,5,1\text{-}CH_3C_6H_3(COCl)SO_2Cl$	$I^{37,\ 38}$	....	218 or 228	....
$4,1\text{-}C_6H_4(CHBrCHBrCOCl)SO_2Cl$	I^{30}	....	208	....

TABLE X (*Continued*)

Sulfonyl Chloride	Reagent and Reference(s)	M.P., °C.	Amide	M.P., °C. Anilide and Reference
2,5,1-n-$C_3H_7C_6H_3(COCl)SO_2Cl$	I[40]	42–43	202–203	....
2,5,1-i-$C_3H_7C_6H_3(COCl)SO_2Cl$	I[40]	55–56	225	....
4,1-$C_6H_4(CH{=}CHCOCl)SO_2Cl$	I[41]	....	218	....
4,1-$C_6H_4(CH_2COOH)SO_2Cl$	II[43]	136	176	....
4,1-$C_6H_4(CH{=}CHCOOH)SO_2Cl$	II[43]	226	250–260	....
1,2,4-$HOC_6H_3(COOH)SO_2Cl$	II[43]	169–171	....	218–220[49]
1,2,5-$CH_3OC_6H_3(COOH)SO_2Cl$	I[51]	149.5	201	....
1,2,4-$C_6H_3(COOH)_2SO_2Cl$	I[42]	167–170	192–202 (decomp.)	....
1,4,6-$CH_3OC_6H_3(COCl)SO_2Cl$	I[51]	70	262	....
1,4,6-$CH_3OC_6H_3(COOH)SO_2Cl$	I[51]	178	....	....
1,2,4-$C_6H_3(COCl)_2SO_2Cl$	I[42]	Liquid	....	....

[1] Basler Chem. Fabr., German pat., 124,407, *Chem. Zentr.*, II, 961 (1901).
[2] Cobb, *Am. Chem. J.*, **35**, 490 (1906).
[3] (*a*) List and Stein, *Ber.*, **31**, 1662 (1898). (*b*) **31**, 1649 (1898).
[4] Humphreys, *Am. Chem. J.*, **30**, 302 (1903).
[5] Holmes, *ibid.*, **25**, 202 (1901).
[6] Remsen and Kohler, *ibid.*, **17**, 330 (1895).
[7] Remsen and Saunders, *ibid.*, **17**, 347 (1895).
[8] Remsen and McKee, *ibid.*, **18**, 794–804 (1896).
[9] Scheiber and Knothe, *Ber.*, **46**, 2254 (1912).
[10] Fritsch, *Ber.*, **30**, 2299 (1896).
[11] Remsen, *Am. Chem. J.*, **17**, 310 (1895).
[12] Wilson, *ibid.*, **30**, 371 (1903).
[13] Bradshaw, *ibid.*, **35**, 338 (1906).
[14] Sohon, *ibid.*, **20**, 271 (1898).
[15] Kreis, *Ann.*, **226**, 383–387 (1895).
[16] Jesurun, *Ber.*, **26**, 2288 (1893).
[17] Walker and Smith, *J. Chem. Soc.*, **89**, 352 (1906).
[18] Blanchard, *Am. Chem. J.*, **30**, 488–494 (1903).
[19] Chambers, *ibid.*, **30**, 388 (1903).
[20] Kastle, *ibid.*, **11**, 182 (1889).
[21] Henderson, *ibid.*, **25**, 10 (1901).
[22] Remsen and Gray, *ibid.*, **19**, 497–510 (1897).
[23] Hollis, *ibid.*, **23**, 235–239 (1900).
[24] Limpricht and v. Uslar, *Ann.*, **106**, 30 (1858).
[25] Wegscheider and Furcht, *Monatsh.*, **23**, 1118 (1902).
[26] Limpricht and v. Uslar, *Ann.*, **102**, 250 (1857).
[27] Ullmann, *Am. Chem. J.*, **16**, 541 (1894).
[28] Böttinger, *Ann.*, **191**, 16, 28 (1878).
[29] Roeters van Lennep, *Z. Chem.*, 69 (1871).
[30] Remsen, Hartman, and Muckenfuss, *Am. Chem. J.*, **18**, 152 (1896).
[31] Otto, *Ann.*, **123**, 223 (1862).
[32] Hopfgartner, *Monatsh.*, **14**, 691 (1893).
[33] Karslake and Huston, *J. Am. Chem. Soc.*, **31**, 1058 (1909).
[34] Karslake and Bond, *ibid.*, **31**, 408 (1909).
[35] Randall, *Am. Chem. J.*, **13**, 261 (1891).
[36] Badische Anilin- und Sodafabrik, German pat., 48,583, *Frdl.*, **2**, **542**.
[37] Fischli, *Ber.*, **12**, 618 (1879).
[38] Meyer and Baur, *Ann.*, **220**, 20 (1883).
[39] Moore, *J. Am. Chem. Soc.*, **25**, 622 (1903).
[40] Widman, *Ber.*, **22**, 2276–2279 (1889).
[41] Palmer, *Am. Chem. J.*, **4**, 163 (1882).

[42] Rée, *Ann.*, **233**, 228 (1886).
[43] Stewart, *J. Chem. Soc.*, **121**, 2555 (1922).
[44] Hirwe and Jambhekar, *J. Indian Chem. Soc.*, **10**, 47 (1033).
[45] Remsen and Coates, *Am. Chem. J.*, **17**, 321 (1895).
[46] Remsen and Holmes, *ibid.*, **30**, 275 (1903).
[47] Remsen and Hunter, *ibid.*, **18**, 811 (1896).
[48] Karslake and Bond, *J. Am. Chem. Soc.*, **38**, 1344 (1916).
[49] Bayer and Co., German pat., 276,331, *Frdl.*, **12**, 173.
[50] Soc. pour l'ind. à Bâle, French pat., 825,728, *C.A.*, **32**, 6667 (1938).
[51] Shah, Bhatt, and Kanga, *J. Chem. Soc.*, 1375 (1933).

TABLE XI

SULFONYL CHLORIDES AND AMIDES OF KETONES

Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C.	
			Amide	Anilide
1,2-$C_6H_5COC_6H_4SO_2Cl$	III^{1,4}	96–97	(Forms sultim)	143–145
2,5, 1-$(C_6H_5CO)(O_2N)C_6H_3SO_2Cl$	I,^{2} III^{2,3,4}	177	....	....
(3-$C_6H_4SO_2Cl)_2CO$	I^{5,6}	137–138 and 121	157	177–178
1,2-$C_6H_4(SO_2Cl)COCH_2Cl$	II^{7,8}	194–195	....	....

[1] Remsen and Saunders, *Am. Chem. J.*, **17**, 354 (1895).,
[2] Hollis, *ibid.*, **23**, 239 (1900).
[3] Henderson, *ibid.*, **25**, 5 (1901).
[4] Norris, *ibid.*, **24**, 487 (1900).
[5] Beckmann, *Ber.*, 8, 992 (1875).
[6] Lapworth, *J. Chem. Soc.*, **73**, 405 (1898).
[7] Weston and Suter, *J. Am. Chem. Soc.*, 61, 389 (1938).
[8] Riess and Frankfurter, *Monatsh.*, **50**, 68 (1928).

TABLE XII

DERIVATIVES OF MISCELLANEOUS BICYCLIC COMPOUNDS

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C.	
			Amide	Anilide and Reference
Indane and Tetralin Derivatives				
$(CH_2)_3{=}C_6H_3$-4-	I^{1}	....	92–93	....
$(CH_2)_3{=}C_6H_3$-5-	I^{1,2}	45–47	135–136	....
$(CH_2)_4{=}C_6H_3$-5-	I^{3,4}	70–72	139–140	144–145^{3}
$(CH_2)_4{=}C_6H_3$-6-	I^{4}	58	135–137	....
$(CH_2)_4{=}C_6H_2Cl$-6,7-	I^{19}	Oil	193–194	....
$(CH_2)_4{=}C_6H_2NO_2$-5,7-	I^{4}	....	189	....
$(CH_2)_4{=}C_6H_2NO_2$-7,5-	I^{4}	....	211–212	....
$(CH_2)_4{=}C_6H(CH_3)_2$-6,7,5-	I^{26}	....	135	....
[1,1-$(CH_3)_2C_4H_6]{=}C_6H(CH_3)_2$-6,7,5-	I^{26}	....	137–138	....
[1,1-$(CH_3)_2C_4H_6]{=}C_6H_2(C_2H_5)$-6,$x$-	I^{26}	....	129–130	....
[2,3-$(CH_3)_2C_4H_6]{=}C_6H_3$-6-	I^{26}	....	143 (*cis*) 210–211 (*trans*)	....
$(CH_2)_4{=}C_6H_2$-5,7-di-	I^{19}	103–104	....	....

TABLE XII (*Continued*)

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C.	
			Amide	Anilide and Reference
Biphenyl Sulfonyl Chlorides				
2-$C_6H_5C_6H_4$-	I[23]	103	....	....
4-$C_6H_5C_6H_4$-	I[5, 23]	115	227–230	125[23]
4,2-$Cl(C_6H_5)C_6H_3$-	I[24]	102	....	....
4-(4-$O_2NC_6H_4)C_6H_4$-	I[6]	178	228	182–183[6]
4-(4-$CH_3CONHC_6H_4)C_6H_4$-	II[32, 33]	180 (dec.)	295–297 (dec.)	....
4-(?)-[2,5-CH_3(*iso*-$C_3H_7)C_6H_3]C_6H_4$-	I[7]	173	....	209[7]
2,5-$Cl(4\text{-}ClC_6H_4)C_6H_3$-	I[8]	194	189	....
4,2-$Br(C_6H_4)C_6H_3$-	I[24, 25]	119	....	....
2,5-$Br(4\text{-}BrC_6H_4)C_6H_3$-	I[6]	131	200	....
4,2-$Br(3\text{-}BrC_6H_4)C_6H_3$-	I[26]	151–152	....	....
2,5-$I(4\text{-}IC_6H_4)C_6H_3$-	I[8]	157	192	....
Biphenyl Disulfonyl Chlorides				
$(2\text{-}C_6H_4SO_2Cl)_2$	I[9, 30]	138	>300	157[9]; 186[30]
$(4,2\text{-}ClC_6H_3SO_2Cl)_2$	I[8]	148	308	....
$(4,2\text{-}BrC_6H_3SO_2Cl)_2$	I[8, 10]	187–190	296	....
$(4,2\text{-}IC_6H_3SO_2Cl)_2$	I[8]	232	>400	....
$(4,2\text{-}O_2NC_6H_3SO_2Cl)_2$	III[9]	202	....	....
$(3\text{-}C_6H_4SO_2Cl)_2$	I,[11] III[31]	127–128	285	182[11]
$(4,3\text{-}ClC_6H_3SO_2Cl)_2$	I[8, 30]	172, 179	286–287	....
$(4,3\text{-}BrC_6H_3SO_2Cl)_2$	I,[8] II[6]	219	332	....
$(4,3\text{-}IC_6H_3SO_2Cl)_2$	I[8]	254	316	....
$(4\text{-}C_6H_4SO_2Cl)_2$	I[5, 17]	203	>300	....
2,4,4′-$(O_2NC_6H_3)(SO_2Cl)C_6H_4SO_2Cl$	III[6]	130–131	....	....
$(2,4\text{-}O_2NC_6H_3SO_2Cl)_2$	III[6]	166	....	....
$(4,2\text{-}CH_3C_6H_3SO_2Cl)_2$	I[30]	117–118	....	....
$(5,2\text{-}CH_3C_6H_3SO_2Cl)_2$	I[12]	228–229	>360 (dec.)	....
Miscellaneous Compounds				
4-$(C_6H_5O)C_6H_4$-1-SO_2Cl	I[21]	45–46	128–129	....
4-$(4\text{-}BrC_6H_4O)C_6H_4$-1-$SO_2Cl$	II[21, 22]	81–82	131–132	....
4,3-$(4\text{-}O_2NC_6H_4O)(NO_2)C_6H_3$-1-$SO_2Cl$	I[34]	134–136.5	188–190	....
2,5-$(2\text{-}O_2NC_6H_4O)(CH_3)C_6H_3$-1-$SO_2Cl$	I[20]	132	....	157[20]
4,3-$[2,4\text{-}(NO_2)_2C_6H_3O](NO_2)C_6H_3$-1-$SO_2Cl$	I[34]	157–159	....	....
$(4\text{-}C_6H_4SO_2Cl)_2O$	II[21, 22]	128–129	158–160	....
$(4,2\text{-}BrC_6H_3SO_2Cl)_2O$	II[26]	241–243	....	....
5,2-$Br(4\text{-}BrC_6H_4O)C_6H_3$-1-$SO_2Cl$	I[26]	128–129	....	....
$(2,4\text{-}O_2NC_6H_3SO_2Cl)_2S$	I[27]	195	....	....
$(3\text{-}C_6H_4SO_2Cl)_2SO_2$	II[23]	174–175	....	....
$(4,3\text{-}CH_3C_6H_3SO_2Cl)_2SO_2$	II[23]	177–178	268	325[23]
$[2,5,3\text{-}(CH_3)_2C_6H_2SO_2Cl]_2SO_2$	II[23]	190	325	....

TABLE XII (*Continued*)

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C. Amide	M.P., °C. Anilide and Reference
Miscellaneous Compounds (*Continued*)				
$4\text{-}(2,1\text{-}HOC_{10}H_6\text{-}S)C_6H_4\text{-}1\text{-}SO_2Cl$	III[29]	160	....	156[29]
$(4\text{-}C_6H_4SO_2Cl)_2CH_2$	I[13]	124	....	178[13]
$4(?)\text{-}[2,5\text{-}CH_3(i\text{-}C_3H_7)C_6H_3CH_2]\text{-}C_6H_4\text{-}1\text{-}SO_2Cl$	I[7]	134	....	88–103[7]
$(3\text{-}C_6H_4SO_2Cl)_2CCl_2$	I[13, 14]	....	....	....
$1,4\text{-}(C_6H_5NH)(O_2N)C_6H_3\text{-}2\text{-}SO_2Cl$	I[15]	102–104	173	....
$1,2\text{-}(C_6H_5NH)(O_2N)C_6H_3\text{-}4\text{-}SO_2Cl$	I[15]	Needles	162	....
$CO(4\text{-}NHC_6H_4SO_2Cl)_2$	II[16]	....	....	....
$4\text{-}(C_6H_5N{=}N)C_6H_4\text{-}1\text{-}SO_2Cl$	I[18]	124.4–125	224.8–225.2	....

[1] Spilker, *Ber.*, **26**, 1541 (1893).

[2] Moschner, *Ber.*, **33**, 743 (1900).

[3] Morgan, Micklethwait, and Winfield, *J. Chem. Soc.*, **85**, 756 (1904).

[4] Schroeter, Svanoe, Einbeck, Geller, and Rubensahm, *Ann.*, **426**, 83 (1922)

[5] Gabriel and Deutsch, *Ber.*, **13**, 386 (1880).

[6] Gabriel and Dambergis, *Ber.*, **13**, 1408 (1880); Novelli and Somaglino, *J. Am. Chem. Soc.*, **63**, 854 (1941).

[7] Klages, *Ber.*, **40**, 2371 (1907).

[8] Courtot and Liu, *Bull. soc. chim.*, [4] **40**, 1047 (1931).

[9] Limpricht, *Ann.*, **261**, 330 (1891).

[10] Limpricht and Rodatz, *Ber.*, **14**, 1361 (1881).

[11] Schultz and Kohlhaus, *Ber.*, **39**, 3342 (1906).

[12] Helle, *Ann.*, **270**, 364 (1892).

[13] Lapworth, *J. Chem. Soc.*, **73**, 408 (1898).

[14] Beckmann, *Ber.*, **8**, 993 (1875).

[15] Fischer, *Ber.*, **24**, 3798 (1891).

[16] Schweitzer and Burr, German pat., 532,399, *C.A.*, **26**, 3262 (1932).

[17] Witt and Truttwin, *Ber.*, **47**, 2786 (1914).

[18] Chrzaszczewska and Dobrowolski, *Roczniki Chem.*, **17**, 411 (1937); *C.A.*, **32**, 1674 (1938).

[19] Schroeter, Erzberger, and Passavant, *Ber.*, **71B**, 1040 (1938).

[20] Tozer and Smiles, *J. Chem. Soc.*, 1897 (1938).

[21] Suter, *J. Am. Chem. Soc.*, **53**, 1112 (1931).

[22] Huntress and Carten, *ibid.*, **62**, 603 (1940).

[23] Pollak, Heimberg-Krauss, Katscher, and Lustig, *Monatsh.*, **65**, 358 (1930).

[24] Courtot, *Compt. rend.*, **198**, 2260 (1934).

[25] Chaix and Rochebovët, *Bull. soc. chim.*, [5] **2**, 273 (1935).

[26] Suter, McKenzie, and Maxwell, *J. Am. Chem. Soc.*, **58**, 717 (1936).

[27] Pollak and Deutscher, *Monatsh.*, **56**, 365 (1930).

[28] Courtot and Chaix, *Compt. rend.*, **193**, 1667 (1931).

[29] Warren and Smiles, *J. Chem. Soc.*, 1040 (1932).

[30] Barber and Smiles, *ibid.*, 1141 (1928).

[31] Steinkopf and Jaeger, *J. prakt. Chem.*, [2] **128**, 63 (1930).

[32] Van Meter, Bianculli, and Lowy, *J. Am. Chem. Soc.*, **62**, 3146 (1940).

[33] Halverstadt and Kumler, *ibid.*, **63**, 624 (1941).

[34] Vorozhtzov, *J. Gen. Chem.* (*U.S.S.R.*), **10**, 935 (1940).

[35] Coulson, *J. Chem. Soc.*, 1306 (1933).

[36] Pope and Bogert, *J. Org. Chem.*, **2**, 276 (1937).

TABLE XIII

Naphthalenesulfonyl Chlorides and Amides

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C. Amide	M.P., °C. Anilide and Reference
$C_{10}H_7$-1-	$I^{3, 85}$	66	150	112^{71}, 152^{88}
$C_{10}H_7$-2-	$I^{1b, c, d, 2, 72}$	76	212–213	132^{71}
1-$FC_{10}H_6$-4-	$I^{3, 104*}$	86	204–205	144^{104}
1-$FC_{10}H_6$-5-	I^{4}	122–123	196–197	....
3-$FC_{10}H_6$-1-	I^{104}	97	133	129^{104}
1-$ClC_{10}H_6$-2-	I^{5}	80	>250	171–172
1-$ClC_{10}H_6$-3-	I^{6}	106	168	....
1-$ClC_{10}H_6$-4-	$I^{1, 9, 85, 89, 90}$	94–95	187	145–146, $143^{89, 90}$
1-$ClC_{10}H_6$-5-	$I^{8, 9, 89, 90}$	95–96	226	138^{90}
1-$ClC_{10}H_6$-6-	$I^{8, 10, 89}$	111–112, 113–115	216	....
1-$ClC_{10}H_6$-7-	$I^{10, 11, 89}$	93–94	185–186	....
1-$ClC_{10}H_6$-8-	$I^{12, 88, 89}$	96–98, 101	196–197, 198	....
2-$ClC_{10}H_6$-1-	I^{89}	74–75	....	....
2-$ClC_{10}H_6$-5-	$I^{10, 13}$	70	214	....
2-$ClC_{10}H_6$-6-	$I^{14, 89}$	109–110	184	....
2-$ClC_{10}H_6$-7-	$I^{10, 11, 15, 89}$	86.5	176	....
2-$ClC_{10}H_6$-8-	$I^{14a, 15, 89}$	129	235	....
1,2-$Cl_2C_{10}H_5$-5-	I^{17}	104–106	217–223	....
1,2-$Cl_2C_{10}H_5$-6-	$I^{18, 19}$	166–168	188–192	....
1,2-$Cl_2C_{10}H_5$-7-	$I^{10, 11, 19}$	123–124	226–227	....
1,2-$Cl_2C_{10}H_5$-8-	I^{19}	138	221	....
1,3-$Cl_2C_{10}H_5$-5-	I^{20}	145–148	272	....
1,3-$Cl_2C_{10}H_5$-7-	I^{18}	121	228	....
1,4-$Cl_2C_{10}H_5$-6-	$I^{18, 19, 21, 22}$	132–134	244	....
1,5-$Cl_2C_{10}H_5$-2-	I^{19}	124	282	....
1,5-$Cl_2C_{10}H_5$-3-	I^{18}	139.5	204	....
1,6-$Cl_2C_{10}H_5$-3-	I^{88}	156	196	....
1,6-$Cl_2C_{10}H_5$-4-	$I^{8, 18}$	151	217	....
1,7-$Cl_2C_{10}H_5$-3-	I^{23}	130	218	....
1,7-$Cl_2C_{10}H_5$-4-	I^{10}	118	226	....
1,8-$Cl_2C_{10}H_5$-3-	$I^{10, 18}$	158	197	....
1,8-$Cl_2C_{10}H_5$-4-	$I^{18, 19}$	114–116	228–229	....
2,3-$Cl_2C_{10}H_5$-5-	I^{18}	142	268	....
2,3-$Cl_2C_{10}H_5$-6-	I^{18}	178	....	....
2,6-$Cl_2C_{10}H_5$-4-	$I^{18, 22}$	236	269	....
2,7-$Cl_2C_{10}H_5$-3-	I^{18}	163.5	218	....
1,2,3-$Cl_3C_{10}H_4$-?-	I^{18}	182	296	....
1,2,4-$Cl_3C_{10}H_4$-?-	I^{18}	157–158	235	....
1,2,7-$Cl_3C_{10}H_4$-?-	I^{20}	173	....	....
1,2,8-$Cl_3C_{10}H_4$-?-	I^{20}	105	....	....
1,3,6-$Cl_3C_{10}H_4$-?-	I^{20}	154	....	....
1-$BrC_{10}H_6$-2-	I^{88}	93–94	....	....

TABLE XIII (*Continued*)

			M.P., °C.	
Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	Amide	Anilide and Reference
1-BrC$_{10}$H$_6$-4-	I[34, 25]	86–87	195	....
1-BrC$_{10}$H$_6$-5-	I[26]	90–94	232–233	....
1-BrC$_{10}$H$_6$-8-	I[88]	110	....	....
2-BrC$_{10}$H$_6$-5-	I[27]	77	217	....
2-BrC$_{10}$H$_6$-1-	I[88]	97	140	....
2-BrC$_{10}$H$_6$-6-	I[27, 28, 29]	124	204–207	....
2-BrC$_{10}$H$_6$-7-	I[27]	100	218	....
2-BrC$_{10}$H$_6$-8-	I[27]	147	209	....
1-BrC$_{10}$H$_6$-?-	I[32]	151	....	....
1,4-Br$_2$C$_{10}$H$_5$-6-	I[31]	109 or 120	237–238	....
1,3-Br$_2$C$_{10}$H$_6$-?-	I[31]	157	....	....
1,3-Br$_2$C$_{10}$H$_6$-?-	I[31]	128	....	....
1,5-Br$_2$C$_{10}$H$_6$-?-	I[31]	175	....	....
1,6-Br$_2$C$_{10}$H$_5$-?-	I[31]	145	....	....
1,7-Br$_2$C$_{10}$H$_5$-?-	I[31]	113	....	....
1-IC$_{10}$H$_6$-2-	I[84]	94	....	....
1-IC$_{10}$H$_6$-4-	I[33, 85]	121, 123–124.5	202, 206.5	136.5[82]
1-IC$_{10}$H$_6$-5-	I[34, 85]	114	236, 239	....
1-IC$_{10}$H$_6$-8-	I[88]	115	187	140[88]
2-IC$_{10}$H$_6$-1-	I[88]	109.5	154	....
2-IC$_{10}$H$_6$-5-	I[27]	92.5	211–213	....
2-IC$_{10}$H$_6$-6-	I[28]	140	220	....
2-IC$_{10}$H$_6$-7-	I[35]	100	210	....
2-IC$_{10}$H$_6$-8-	I[35]	164–165	240	....
1-O$_2$NC$_{10}$H$_6$-3-	I[36]	139.5	225	....
1-O$_2$NC$_{10}$H$_6$-4-	I,[12, 79] III[96]	99	188	...[79]
1-O$_2$NC$_{10}$H$_6$-5-	I,[1b, 37, 79] III[111]	113	255	...[79]
1-O$_2$NC$_{10}$H$_6$-6-	I,[38, 39] III[103]	125–126	180–184	....
1-O$_2$NC$_{10}$H$_6$-7-	I,[1b, 39, 40, 79] III[103]	169	216 or 223	172–173[1b, 79]
1-O$_2$NC$_{10}$H$_6$-8-	I,[1b, 79] III[1f, 97, 111]	161, 165	185, 191	178, 173[1b, 29]
2-O$_2$NC$_{10}$H$_6$-5-	I[41]	127	223–224	....
2-O$_2$NC$_{10}$H$_6$-8-	I[41]	169–170	261–262	....
1,8-(O$_2$N)$_2$C$_{10}$H$_6$-3-	III[43]	145	272	....
1,4-(O$_2$N)$_2$C$_{10}$H$_6$-7-	III[48]	118–119	....	....
1,2-O$_2$N(Cl)C$_{10}$H$_5$-5-	III[19]	112	214	....
1,2-O$_2$N(Cl)C$_{10}$H$_6$-6-	III[19]	161	203	....
1,2-O$_2$N(Cl)C$_{10}$H$_5$-7-	III[11]	219	247	....
1,2-O$_2$N(Cl)C$_{10}$H$_6$-8-	III[19]	190	226	....
1,4-O$_2$N(Cl)C$_{10}$H$_5$-6-	III[19]	116	208	....
1,4-O$_2$N(Cl)C$_{10}$H$_5$-7-	III[19]	161	188	151[19]
1,5-O$_2$N(Cl)C$_{10}$H$_5$-6-	III[19]	151	220	....
1,5-O$_2$N(Cl)C$_{10}$H$_6$-7-	III[42]	130	188	....
1,5-O$_2$N(Cl)C$_{10}$H$_5$-8-	III[19]	150	233	....
1,8-O$_2$N(Cl)C$_{10}$H$_6$-2-	III[19]	129	245	....
1,8-O$_2$N(Cl)C$_{10}$H$_5$-5-	III[19]	127	181	....

TABLE XIII (*Continued*)

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C.	
			Amide	Anilide and Reference
2,1-$O_2N(Cl)C_{10}H_5$-5-	III[42]	118	220	....
2,8-$O_2N(Cl)C_{10}H_5$-7-	III[19]	182	231	....
1,4-$O_2N(Cl)C_{10}H_5$-8(?)-	III[42]	134	....	....
4,5-$(O_2N)_2C_{10}H_5$-1-	I[112]	152.5	....	....
1,4,5-$(O_2N)_2ClC_{10}H_4$-8-	III[19]	184	....	....
?,?,1-$(O_2N)_2ClC_{10}H_4$-2-	III[19]	235	....	....
2-$HOC_{10}H_6$-1-	III[73]	124	....	....
1-$HOC_{10}H_6$-4-	....	....	....	199–200[74]
1-$C_2H_5OCOOC_{10}H_6$-2-	I[113]	127–128	....	....
1-$CH_3COOC_{10}H_6$-2-	I[72]	87.5	....	158[73]
1-$CH_3COOC_{10}H_6$-5-	I[44, 79]	129	....	....
2-$CH_3COOC_{10}H_6$-6-	I[45, 79]	103–107	....	95[45]
1-$HOC_{10}H_6$-5-	....	....	....	200[79]
2-$CH_3COOC_{10}H_6$-8-	I[45]	129	....	....
2-$CH_3COOC_{10}H_6$-1-	I[73]	115	....	....
1-$C_2H_5OCOOC_{10}H_6$-4-	I, II[63]	83	....	149[74]
1-$C_2H_5OCOOC_{10}H_6$-5-	....	....	....	129[75]
2-$C_2H_5OCOOC_{10}H_6$-6-	I[76]	118	....	130[76]
2-$C_2H_5OCOOC_{10}H_6$-8-	I,[45] II[63]	118	....	195[45]
2-$C_2H_5OC_{10}H_6$-1-	I[47]	115–116	158	187[47]
1-$C_2H_5OC_{10}H_6$-4-	I[46]	101	167	178[46]
2-$CH_3OC_{10}H_6$-3-	I[99]	137–138	113	173–174[99]
2-$CH_3OC_{10}H_6$-6-	I[47]	93	199	79–80[47]
2-$C_2II_5OC_{10}H_6$-6-	I[47]	107.5	183	152–153[47]
1,2-$Br(C_2H_5O)C_{10}H_5$-6-	I[47]	131–132	191	....
1,2-$O_2N(C_2H_5O)C_{10}H_5$-6-	I[47]	146	218	....
1,2-$(COOH)(HO)C_{10}H_5$-6-	II[77]	....	....	....
2-$C_2H_5OC_{10}H_6$-7-	I[47]	103	172	153[47]
2-$CH_3OC_{10}H_6$-8-	I[47]	135–137	153	196[47]
2-$C_2H_5OC_{10}H_6$-8-	I[47]	93	165	158[47]
2,1-$C_2H_5O(O_2N)C_{10}H_5$-6-	I[47]	146	218	....
2,?-$C_2H_6O(O_2N)C_{10}H_5$-8-	I[47]	155	173–174	....
2-$C_6H_5CON(CH_3)C_{10}H_6$-6-	I[114]	115–116	225–226	....
2-$CH_3CON(CH_3)C_{10}H_6$-6-	I[114]	142–143	184–185	....
2-$(CH_3)_2NC_{10}H_6$-5-	II[86]	86 or 108–110	....	....
1-$CH_3CONHC_{10}H_6$-4-	I,[66, 67] II[68, 86]	170	241	....
1-$C_6H_5CONHC_{10}H_6$-6-	II[66, 86]	185–186	....	....
1-$C_6H_5SO_2NHC_{10}H_6$-4-	I[66]	171	....	....
2,5-$CH_3CONH(HO)C_{10}H_5$-7-	II[86]	180 (dec.)	....	....
2,8-$CH_3CONH(HO)C_{10}H_6$-6-	II[86]	180 (dec.)	....	....
4,7-$C_6H_6COO(C_6H_5CONH)$-$C_{10}H_5$-2-	I[115]	151	....	....
1-$(CN)C_{10}H_6$-2-	I[45]	143	....	....
1-$(CN)C_{10}H_6$-8-	I[88]	139	334–336	....
2-$(CN)C_{10}H_6$-1-	I[63]	92	>300	....

TABLE XIII (*Continued*)

			M.P., °C.	
Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	Amide	Anilide and Reference
2-$C_{10}H_6(COCl)$-3-	I[49]	288	....	....
1-$CH_3C_{10}H_6$-3-	I[100]	124–125	143–144	....
1-$CH_3C_{10}H_6$-4-	I[50, 89, 93]	80–81	174–177	158[50]
1-$CH_3C_{10}H_6$-5-	I[100]	....	176–178	....
1-$CH_3C_{10}H_6$-6-	I[101]	120–121	188–189	133–134[101]
2,5-$CH_3(O_2N)C_{10}H_5$-1-	III[93]	84–85	....	....
2,8-$CH_3(O_2N)C_{10}H_5$-1-	III[96]	145	....	....
1,5-$CH_3(O_2N)C_{10}H_5$-4-	III[89, 94]	162–163, 170	228	257–258[89]
1-$CH_3C_{10}H_6$-7-	I[81c, 102]	107, 88	113, 116	149[81c]
2-$CH_3C_{10}H_6$-1-	I[93]	83–85	124	....
2-$CH_3C_{10}H_6$-6-	I[51]	97–98	205–206	....
2-$CH_3C_{10}H_6$-8-	I[93, 95]	96	195–196	162–164[95]
1,8-$CH_3(O_2N)C_{10}H_5$-4-	III[89, 94]	115–116	....	131–132[89]
2-$C_2H_5C_{10}H_6$-6-	I[93]	69–69.5	190–191	....
2-*i*-$C_3H_7C_{10}H_6$-1-	I[92]	61	140	....
1-$C_6H_5CH_2C_{10}H_6$-4-	I[70]	104–105	164–165	....
1,6-$(CH_3)_2C_{10}H_5$-4-	I[93]	....	185	....
6,7-$(CH_3)_2C_{10}H_5$-1-	II[116]	....	208	....
2,6-$(CH_3)_2C_{10}H_5$-1-	I[81c]	116–117	124–125	....
2,6-$(CH_3)_2C_{10}H_5$-7-	I[52, 80, 81d]	....	265–266	....
2,6-$(CH_3)_2C_{10}H_5$-8-	I[52, 81]	105–107	207	....
?,?,-$(i\text{-}C_3H_7)_2C_{10}H_5$-1-	I[86]	119	151	....
2,7-$(CH_3)_2C_{10}H_5$-3-	I[88]	....	197–198	....
1,6-$(i\text{-}C_3H_7)_2C_{10}H_5$-3(or 7)-	I[93]	71	179–180	....
1,8-$(C_6H_5CH_2)_2C_{10}H_5$-4-	I[91]	151	167	....
1,4-$(C_6H_5CH_2)(C_6H_5CO)$-$C_{10}H_5$-5-	I[87]	155–156	182–183	....
1-$(C_6H_5CO)C_{10}H_6$-4(?)-	I[87]	117–119	199–200	175–177
1-$C_{10}H_6(SO_2F)$-5-	II[109]	174	252–253	....
2-$C_{10}H_6(SO_2F)$-6-	II[109]	114–116	208	....
	Disulfonyl Chlorides			
$C_{10}H_6$-1,3-	I[80, 84]	137–138	....	....
$C_{10}H_6$-1,4-	I[88, 88]	160	269, 273	179[78]
$C_{10}H_6$-1,5-	I,[83, 65, 82] II[105, 106]	183	....	247–248[106]
$C_{10}H_6$-1,6-	I[65, 84, 107]	127–129	....	....
$C_{10}H_6$-1,7-	I[53, 107]	122.5	....	....
$C_{10}H_6$-2,6-	I[53, 67, 38]	225–226	305	....
$C_{10}H_6$-2,7-	I[13, 65, 67, 68]	157–158	242–243	....
1-$ClC_{10}H_5$-2,7-	I[13]	144	....	....
1-$ClC_{10}H_5$-3,5-	I[80]	130	....	....
1-$ClC_{10}H_5$-3,6-	I[88]	114 and 127	....	....
1-$ClC_{10}H_5$-3,8-	I[88]	110	....	....
1-$ClC_{10}H_5$-4,6-	I[53]	127	....	....

TABLE XIII (*Continued*)

Aryl Group of Sulfonyl Chloride	Reagent(s) and Reference(s)	M.P., °C.	M.P., °C. Amide	M.P., °C. Anilide and Reference
		Disulfonyl Chlorides (Continued)		
1-ClC$_{10}$H$_5$-4,7-	I[53]	107	....	....
1-ClC$_{10}$H$_5$-4,8-	I[53]	135	....	....
2-ClC$_{10}$H$_5$-1,5-	I[53]	158	....	....
2-ClC$_{10}$H$_5$-1,6-	I[53, 59]	125	....	....
2-ClC$_{10}$H$_5$-3,6-	I[53]	165	....	....
2-ClC$_{10}$H$_5$-3,7-	I[53]	176	....	....
2-ClC$_{10}$H$_5$-4,6-	I[53]	148	....	....
2-ClC$_{10}$H$_5$-4,7-	I[53]	174	....	....
2-ClC$_{10}$H$_5$-5,7-	I[53]	156	....	....
2-ClC$_{10}$H$_5$-6,8-	I[28, 53]	170	250	....
1-O$_2$NC$_{10}$H$_5$-3,6-	I[13, 53]	140–141	285–287	....
1-O$_2$NC$_{10}$H$_5$-3,7-	I[53]	190–192	300	....
1,8-(O$_2$N)$_2$C$_{10}$H$_4$-3,6-	I[53]	219–220	306	....
1-HOC$_{10}$H$_5$-2,4-	II[44, 64]	149	....	228[64]
1-C$_2$H$_5$OCOOC$_{10}$H$_5$-3,6-	I[110]	95	....	....
1-C$_2$H$_5$OCOOC$_{10}$H$_5$-3,8-	I[110]	180–181	....	....
1-C$_2$H$_5$OCOOC$_{10}$H$_5$-4,7-	I[110]	120	....	....
1-C$_2$H$_5$OCOOC$_{10}$H$_5$-4,8-	I[110]	177–179	....	....
2-HOC$_{10}$H$_5$-1,6-	II[44]	111	....	191[45]
2-HOC$_{10}$H$_5$-6,8-	II[44]	161–162	....	195[45]
2-HOC$_{10}$H$_5$-1,5-	II[45]	177	231	....
2-HOC$_{10}$H$_5$-1,7-	II[68]	169	....	233[44]
2-HOC$_{10}$H$_5$-3,6-	II[109]	112–113	....	....
2-C$_2$H$_5$OC$_{10}$H$_5$-1,6-	I[47]	51	253–254	127[47]
2-C$_2$H$_5$OC$_{10}$H$_5$-3,6-	I[47]	121	....	....
2-C$_2$H$_5$OC$_{10}$H$_5$-6,8-	I[47]	158	....	....
2-C$_2$H$_5$OCOOC$_{10}$H$_5$-3,6-	II[45]	125	....	....
2-C$_2$H$_5$OCOOC$_{10}$H$_5$-6,8-	II[45]	131	178	....
1-H$_2$NC$_{10}$H$_5$-3,6-	II[108]	149	....	....
1,8-CH$_3$CONH(OH)C$_{10}$H$_4$-3,6-	II[68, 85]	188–189	....	....
1,8-CH$_3$CONH(OH)C$_{10}$H$_4$-4,6-	II[68, 86]	145–147	....	....
1,8-(NHCOO)C$_{10}$H$_4$-3,6-	II[44]	214–216	....	....
1,2-(NHCOO)C$_{10}$H$_4$-?,?-	II[53]	262–263	....	....
1,2-(N$_2$O)C$_{10}$H$_4$-4,?-	II[68]	131–132	....	....
		Trisulfonyl Chlorides		
C$_{10}$H$_5$-1,3,5-	I[61]	146	....	....
C$_{10}$H$_5$-1,3,6-	I[53]	191	....	....
C$_{10}$H$_5$-1,4,5-	I[78]	156–157	....	....
C$_{10}$H$_5$-2,3,6-	I[85]	200	....	....
1-ClC$_{10}$H$_4$-2,4,7-	I[53]	215	....	....
1-HOC$_{10}$H$_4$-2,4,7-	II[45, 64, 110]	172–174	....	228[44, 64]
1-HOC$_{10}$H$_4$-4,6,8-	II[110]	....	....	....
2-HOC$_{10}$H$_4$-3,5,8-	II[44]	196	....	152–155[44]

[1] (*a*) Kimberly, *Ann.*, **114**, 135 (1860). (*b*) Erdmann and Süvern, *Ann.*, **272**, 233–250 (1893). (*c*) Maikopar, *Z. Chem.*, 711 (1869). (*d*) Otto, Rössing, and Tröger, *J. prakt. Chem.*, [2] **47**, 99 (1893). (*e*) Remsen and Comstock, *Am. Chem. J.*, **5**, 106 (1883). (*f*) Joy and Bogert, *J. Org. Chem.*, **1**, 236 (1936).

[2] Cleve, *Bull. soc. chim.*, [2] **26**, 257 (1876); Bourgeois, *Rec. trav. chim.*, **18**, 439 (1899); Krafft and Roos, *Ber.*, **25**, 2261 (1892); Fischer and Bergell, *Ber.*, **35**, 3779 (1902).

[3] Mauzelius, *Öfersigt af K. Vetenskapps-Akademiens forhandlingar* (Stockholm), **2**, 441 (1890).

[4] Mauzelius, *Ber.*, **22**, 1844 (1889).

[5] Cleve, *Ber.*, **24**, 3473 (1891).

[6] Cleve, *Ber.*, **21**, 3273 (1888).

[7] Cleve, *Bull. soc. chim.*, [2] **26**, 242 (1876); Arnell, *Ber.*, **17R**, 48 (1884).

[8] Cleve, *Bull. soc. chim.*, [2] **26**, 540 (1876).

[9] Cleve, *Ber.*, **20**, 72–75 (1887).

[10] Armstrong and Wynne, *Chem. News*, **59**, 189 (1889).

[11] Cleve, *Ber.*, **25**, 2481 (1892).

[12] Cleve, *Ber.*, **23**, 959–962 (1890).

[13] Armstrong and Wynne, *Chem. News*, **71**, 254–255 (1895).

[14] (*a*) Arnell, *Bull. soc. chim.*, [2] **45**, 184 (1886). (*b*) Forsling, *Ber.*, **20**, 20 (1887).

[15] Morton, *Öfersigt af K. Vetenskapps-Akademiens forhandlingar* (Stockholm), **10**, 414 (1892).

[16] Forsling, *Ber.*, **21**, 2802 (1888).

[17] Hellström, *Öfersigt af K. Vetenskapps-Akademiens forhandlingar* (Stockholm), **2**, 114 (1889).

[18] Armstrong and Wynne, *Chem. News*, **61**, 273–5 (1890).

[19] Cleve, *Chem.-Ztg.*, **17**, 398 (1893).

[20] Widmann, *Ber.*, **12**, 2229 (1879).

[21] Widmann, *Ber.*, **12**, 961 (1879).

[22] Arnell, dissertation, Upsala, 1889, p. 37.

[23] Armstrong and Wynne, *Chem. News*, **76**, 69 (1897).

[24] Otto, *Ann.*, **147**, 185 (1868).

[25] Jolin, *Bull. soc. chim.*, [2] **28**, 516 (1877).

[26] Mauzelius, *Ber.*, **20**, 3405 (1887).

[27] Sindall, *Chem. News*, **60**, 58 (1889).

[28] Houlding, *ibid.*, **59**, 227 (1889).

[29] Forsling, *Ber.*, **22**, 1400 (1889).

[30] Armstrong and Wynne, *Chem. News*, **71**, 254 (1895).

[31] Armstrong and Rossiter, *ibid.*, **65**, 58 (1892).

[32] Armstrong and Williamson, *ibid* , **54**, 256 (1886).

[33] Armstrong, *ibid.*, **56**, 241 (1887).

[34] Mauzelius, *Ber.*, **22**, 2820 (1889).

[35] Armstrong and Wynne, *Chem. News*, **20**, 58 (1889).

[36] Cleve, *Ber.*, **19**, 2179 (1886).

[37] Cleve, *Bull. soc. chim.*, [2] **24**, 510 (1875).

[38] Cleve, *ibid.*, [2] **26**, 446 (1876).

[39] Palmaer, *Ber.*, **21**, 3263 (1888).

[40] Cleve, *Bull. soc. chim.*, [2] **29**, 414 (1878).

[41] Kappeler, *Ber.*, **45**, 633 (1912).

[42] Cleve, *Chem.-Ztg.*, **17**, 748 (1893).

[43] Höchster Farbwerke, German pat., 117,268, *Frdl.*, 6, 179.

[44] Pollak, Gebauer-Fülnegg, and Blumenstock-Halward, *Monatsh.*, **49**, 127 (1928).

[45] Pollak and Blumenstock-Halward with Schlesinger, Weinmayr, and Winter, *ibid.*, **49**, 203 (1928)

[46] Witt and Schneider, *Ber.*, **84**, 3181 (1901).

[47] Lapworth, *Chem. News*, **71**, 205 (1895).

[48] Kalle and Co., German pat., 239,093, *Frdl.*, **10**, 489; Kalcher, *Ann.*, **414**, 245 (1917).

[49] Kaufmann and Zobel, *Ber.*, **55B**, 1503 (1922).

[50] Elbe and Christ, *J. prakt. Chem.*, [2] **106**, 17 (1923).

[51] Dziewoński, Schoenowna, and Waldmann, *Ber.*, **58B**, 1212 (1925).

[52] Weissgerber and Kruber, *Ber.*, **52**, 349 (1919).

[53] Armstrong and Wynne, *Chem. News*, **61**, 93 (1890); **62**, 163 (1890).

[54] Dressel and Kothe, *Ber.*, **27**, 1197 (1894).

[55] Armstrong and Wynne, *Chem. News*, **67**, 299 (1893).

[56] Armstrong, *Ber.*, **15**, 205 (1882).

[57] Ebert and Merz, *Ber.*, **9**, 507 (1876).

[58] Alén, *Ber.*, **17R**, 436 (1884).

[59] Forsling, *Ber.*, **21**, 3498 (1888).

[60] Armstrong and Wynne, *Chem. News*, **73**, 55 (1896).

[61] Gattermann, *Ber.*, **32**, 1159 (1899).

[62] Gebauer-Fülnegg and Riesenfeld, *Monatsh.*, **47**, 185 (1926).

[63] Gebauer-Fülnegg and Schlesinger, *Ber.*, 61B, 781 (1928).

[64] Gebauer-Fülnegg and Glückmann, *Monatsh.*, **53** and **54**, 100 (1929).

[65] Pollak, Gebauer-Fülnegg, and Blumenstock-Halward, *ibid.*, **53–54**, 83 (1929).

[66] Schroeter, *Ber.*, **39**, 1563 (1906).

[67] Cleve, *Ber.*, **23**, 961 (1890).

[68] Schweitzer and Burr, German pat., 532,399, *C.A.*, **26**, 3262 (1932); Goldyrev and Postovskii, *J. Applied Chem.* (*U.S.S.R.*), **11**, 316 (1938); *C.A.*, **32**, 5800 (1938).

[69] Steiger, *Helv. Chim. Acta*, **13**, 173 (1930); **17**, 1142 (1934).

[70] Dziewoński and Dziecielewski, *C.A.*, **22**, 2164 (1928).

[71] Carleson, *Bull. soc. chim.*, [2] **27**, 360 (1877).

[72] Zincke and Eismayer, *Ber.*, **51**, 757 (1918).

[73] Anschütz, *Ann.*, **415**, 93 (1918).

[74] Zincke and Ruppersberg, *Ber.*, **48**, 123 (1915).

[75] Rennert, *Ber.*, **48**, 462 (1915).

[76] Zincke and Dereser, *Ber.*, **51**, 355 (1918).

[77] Bayer and Co., German pat., 278,091, *Frdl.*, **12**, 178.

[78] Gattermann, *Ber.*, **32**, 1154 (1899).

[79] Heller, *J. prakt. Chem.*, [2] **121**, 193 (1929).

[80] I. G. Farbenind. A.-G., British pat., 462,337, *C.A.*, **31**, 5595 (1937).

[81] (*a*) I. G. Farbenind. A.-G., British pat., 462,664, *C.A.*, **31**, 6023 (1937). (*b*) French pat., 807,830, *C.A.*, **31**, 6023 (1937). (*c*) French pat., 807,831, *C.A.*, **31**, 6023 (1937); Schumacher, U. S. pat., 2,107,910, *C.A.*, **32**, 2546 (1938). (*d*) French pat., 807,841, *C.A.*, **31**, 6023 (1937). (*e*) French pat., 807,842, *Ber.*, **31**, 6023 (1937); Sieglitz, U. S. pat., 2,107,911, *Ber.*, **32**, 2546 (1938).

[82] Goldstein, Blezinger, and Fischer, *Helv. Chim. Acta*, **20**, 218 (1937).

[83] Levy, *Ann. chim.*, [11] **9**, 78 (1938).

[84] Barber and Smiles, *J. Chem. Soc.*, 1141 (1928).

[85] Cumming and Muir, *J. Roy. Tech. Coll. Glasgow*, **3**, 223 (1934).

[86] Schweitzer and Burr, U. S. pat., 1,939,025, *C.A.*, **28**, 1361 (1934).

[87] Dziewoński and Moszew, *Roczniki Chem.*, **11**, 169 (1931); *C.A.*, **26**, 132 (1932).

[88] Cumming and Muir, *J. Roy. Tech. Coll. Glasgow*, **3**, 562 (1936); *C.A.*, **30**, 4491 (1936).

[89] Beattie and Whitmore, *J. Am. Chem. Soc.*, **55**, 1547, 1567 (1933).

[90] Ferrero and Bolliger, *Helv. Chim. Acta*, **11**, 1144 (1928).

[91] Dziewoński and Moszew, *Roczniki Chem.*, **9**, 361 (1929); *C.A.*, **23**, 3923 (1929).

[92] Meyer and Bernhauer, *Monatsh.*, **53** and **54**, 721 (1929).

[93] Veselý and Páč, *Collection Czechoslov. Chem. Comm.*, **2**, 471 (1930).

[94] Veselý, Šturša, Olejníček, and Rein, *ibid.*, **1**, 493 (1929).

[95] Dziewoński and Wulffsohn, *Bull. intern. acad. polonaise*, **1930A**, 143; *C.A.*, **25**, 1514 (1931).

[96] Brunetti, *J. prakt. Chem.*, [2] **128**, 44 (1930).

[97] Steiger, *Helv. Chim. Acta*, **17**, 794 (1934).

[98] Cohen and Smiles, *J. Chem. Soc.*, 209 (1929).

[99] Holt and Mason, *ibid.*, 377 (1931).

[100] Veselý and Šturša, *Collection Czechoslov. Chem. Comm.*, **3**, 328 (1931).

[101] Dziewoński and Otto, *Bull. intern. acad. polonaise*, **1935A**, 201; *C.A.*, **30**, 2561 (1936).

[102] Dziewoński and Kowalczyk, *ibid.*, **30**, 5213 (1936).

[103] Vorozhtov and Gribov, *J. Gen. Chem.* (*U.S.S.R.*), **2**, 929 (1932).

[104] Schiemann, Gueffroy, and Winkelmüller, *Ann.*, **487**, 270 (1931).

[105] Rodionov, *Bull. soc. chim.*, **45**, 109 (1929); Klarmann, German pat., 466,441, *C.A.*, **23**, 2192 (1929).

[106] Corbellini and Albenga, *Gazz. chim. ital.*, **61**, 111 (1931).

[107] Ufimtsev and Krivoshliikova, *J. prakt. Chem.*, [2] **140**, 172 (1934).

[108] Ostroshinskaya, *C.A.*, **30**, 7567 (1936).

[109] Steinkopf *et al.*, *J. prakt. Chem.*, [2] **117**, 1 (1927).

[110] Gebauer-Fülnegg and Haemmerle, *J. Am. Chem. Soc.*, **53**, 2648 (1931).

[111] Reissert, *Ber.*, **55B**, 858 (1922).

[112] Friedländer, Karamessinis, and Schenk, *Ber.*, **55B**, **45** (1922).

[113] Lesser and Gad, *Ber.*, **58B**, 2551 (1925).

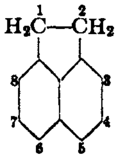
[114] Morgan and Rooke, *J. Soc. Chem. Ind.*, **41**, 1 (1922).

[115] Konig and Haller, *J. prakt. Chem.*, [2] **101**, 38 (1920).

[116] Coulson, *J. Chem. Soc.*, 1305 (1938).

TABLE XIV

SULFONYL CHLORIDES AND AMIDES OF ACENAPHTHENE



Aryl Group of Sulfonyl Chloride	Reagent and Reference	M.P., °C.	M.P. of Amide, °C.
$C_{12}H_9$-3-	I[1]	113–114	....
$C_{12}H_9$-5-	I[2]	109–111	222
5-Br$C_{12}H_8$-"α"-	I[4]	134–135	137–138
5-Br$C_{12}H_8$-"β"-	I[4]	192–193	233–234
5-$O_2NC_{12}H_8$-7-	I[3]	....	....
6-$O_2NC_{12}H_8$-3-	I[2]	....	....
5-$O_2NC_{12}H_7$-?,?-di-	I[4]	181–182	289

[1] Dziewoński, Grünberg, and Schoen, *C.A.*, **25**, 5419 (1931).
[2] Dziewo´ski, Krasowska, and Schoenówna, *C.A.*, **27**, 719 (1933).
[3] Dziewoński and Orzelski, *C.A.*, **22**, 1160 (1928).
[4] Dziewoński, Schoen, and Glasner, *C.A.*, **25**, 1518 (1931).

TABLE XV

DERIVATIVES OF ANTHRACENE AND ANTHRAQUINONE

Aryl Group of Sulfonyl Chloride	Reagent and Reference(s)	M.P., °C.	M.P., °C. Amide	M.P., °C. Anilide and Reference
		A. Anthracene Derivatives		
$C_{14}H_9$-1-	I[15]	....	...	....
$C_{14}H_9$-2-	I[1, 13, 18]	122, 113.5	261	150[1]
$C_{14}H_5Br_4$-2-	III[1]	125	...	....
9,10-$Cl_2C_{14}H_7$-2-	I[14]	221	279	248[14]
$C_{14}H_8$-1,5-di-	I[8]	249	>360	293[8]
$C_{14}H_8$-1,8-di-	I[8]	225	333	224[8]
		B. Anthraquinone Derivatives		
$C_{14}H_7O_2$-1-	I[8, 10]	216–218	...	214–216[5, 10]
$C_{14}H_7O_2$-2-	I[8, 5, 6]	243–244	...	....
1-Cl$C_{14}H_6O_2$-5-	I[8]	243–244	...	....
1-Cl$C_{14}H_6O_2$-6-	I[8]	207–208	...	....
1-Cl$C_{14}H_6O_2$-7-	I[8]	200–201	...	....
1-(O_2N)$C_{14}H_6O_2$-5-	I[10]	277	...	....
1-(O_2N)$C_{14}H_6O_2$-6-	I[8]	194	...	....
1-(O_2N)$C_{14}H_6O_2$-8-	I[10]	245	...	....
1-(HO)$C_{14}H_5O_2$-4-	III[11]	246	...	199[11]
2-$H_2NC_{14}H_6O_2$-3-	I[8]	208	...	....
1,2-(H_2N)Cl$C_{14}H_5O_2$-4-	III[11]	230	...	210[11]

TABLE XV (*Continued*)

Aryl Group of Sulfonyl Chloride	Reagent and Reference(s)	M.P., °C.	M.P., °C. Amide	M.P., °C. Anilide and Reference
B. Anthraquinone Derivatives (Continued)				
1,4-$(H_2N)BrC_{14}H_6O_2$-2-	I[9]	209–210	...	....
2-$CH_3C_{14}H_6O_2$-1-	I[10, 12]	165	...	132–133[12]
$C_{14}H_6O_2$-1,5-di-	I[5, 7]	265–270 (dec.)	...	269–270[5]
$C_{14}H_6O_2$-1,6-di-	I[5]	197–198 (dec.)	...	227–228[5]
$C_{14}H_6O_2$-1,7-di-	I[5]	231–232	...	237–238[5]
$C_{14}H_6O_2$-1,8-di-	I[5]	222–223	...	237–238[5]
$C_{14}H_6O_2$-2,6-di-	I[5, 5]	250	321	....
$C_{14}H_6O_2$-2,7-di-	I[5, 6]	186	192	....

[1] Heffter, *Ber.*, **27**, 2258 (1894).

[2] Lampe, *Ber.*, **42**, 1417 (1909).

[3] MacHoul, *Ber.*, **13**, 692 (1880).

[4] Claus, *Ber.*, **15**, 1516 (1882).

[5] Fierz-David, Krebser, and Anderau, *Helv. Chim. Acta*, **10**, 197 (1927).

[6] Graebe and Liebermann, *Ann.*, **160**, 131 (1871).

[7] Liebermann and Dehnst, *Ber.*, **12**, 1288 (1879).

[8] Goldberg, *J. Chem. Soc.*, 1771 (1931).

[9] Kränzlein, Schlichenmaier, and Schörnig, German pat., 580,648, *C.A.*, **28**, 1053 (1934); U. S. pat., 1,973,001, *C.A.*, **28**, 6726 (1934).

[10] Ullmann and Kertész, *Ber.*, **52B**, 551 (1919).

[11] Fries and Schürmann, *Ber.*, **52B**, 2189 (1919).

[12] Locher and Fierz, *Helv. Chim. Acta*, **10**, 642 (1927).

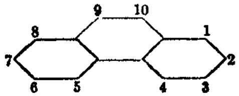
[13] Federov and Sheludyakova, *J. Gen. Chem.* (*U.S.S.R.*), **8**, 1699 (1938); *C.A.*, **33**, 4981 (1939).

[14] Federov, *J. Gen. Chem.* (*U.S.S.R.*), **6**, 444 (1936); *C.A.*, **30**, 6360 (1936).

[15] Battegay and Brandt, *Bull. soc. chim.*, **33**, 1667 (1923).

TABLE XVI

Sulfonyl Chlorides and Amides of Phenanthrene



Sulfonyl Chloride	Reagent and Reference(s)	M.P., °C.	M.P., °C. Amide	M.P., °C. Anilide and Reference
2-$C_{14}H_9SO_2Cl$	I[8]	156	253–254	157–158[3]
3-$C_{14}H_9SO_2Cl$	I[1, 2]	110–111	189–190	161[1]
9-$C_{14}H_9SO_2Cl$	I[1, 7]	125–127	193.5	165[1]
9,3-$ClC_{14}H_8SO_2Cl$	I[4]	196–197	281–282	197–198[4, 11]
10,3-$ClC_{14}H_8SO_2Cl$	I[9]	171	....	....
9,3-$BrC_{14}H_8SO_2Cl$	I[6]	186–187	280–281	185–186 and 193[5, 11]
10,3-$BrC_{14}H_8SO_2Cl$	I[8]	199–200	267	207[4]
1,7,6-$CH_3(i\text{-}C_3H_7)C_{14}H_7SO_2Cl$	I[8, 10]	146–148	206–208	....
3,9-$C_{14}H_8(SO_2Cl)_2$	I[8]	220–221	....	....
9,10-Dihydro Derivative				
2-$C_{14}H_{11}SO_2Cl$	I[12]	137	....	....

[1] Werner, *Ann.*, **321**, 267 (1902).
[2] Sandqvist, *Ann.*, **369**, 113 (1909).
[3] Sandqvist, *Ann.*, **379**, 85 (1911).
[4] Sandqvist, *Ann.*, **417**, 13–27 (1918).
[5] Sandqvist and Hagelin, *Ber.*, **51**, 1524 (1918).
[6] Sandqvist, *Ann.*, **398**, 133 (1913).
[7] Sandqvist, *Ann.*, **392**, 85 (1912).
[8] Sandqvist, *Ber.*, **50**, 776 (1917).
[9] Komppa and Wahlforss, *J. Am. Chem. Soc.*, **52**, 5009 (1930).
[10] Hasselstrom and Bogert, *ibid.*, **57**, 1579 (1935).
[11] Sandqvist, *Ber.*, **53B**, 168 (1920).
[12] Mosettig and Stuart, *J. Am. Chem. Soc.*, **61**, 1 (1939).

TABLE XVII

SULFONYL CHLORIDES AND AMIDES OF PYRIDINE

Sulfonyl Chloride	Reagent and Reference	M.P., °C.	M.P., °C. of Amide
3-$C_5H_4N \cdot SO_2Cl$	I[1]	....	110–111
2-$C_5H_4N \cdot SO_2Cl$	III[4]	....	....
6,3-$ClC_5H_3N \cdot SO_2Cl$	I[2, 3]	51	158–159
2,3,5-$ClBrC_5H_2N \cdot SO_2Cl$	I[3]	72	150

[1] Machek, *Monatsh.*, **72**, 77 (1938).
[2] Naegeli, Kündig, and Brandenburger, *Helv. Chim. Acta*, **21**, 1746 (1938).
[3] Binz and Räth, *Ann.*, **487**, 105 (1931).
[4] Kränzlein and Hopff, German pat., 574,836, *C.A.*, **27**, 4543 (1933).

PHYSICAL PROPERTIES OF SULFONYL CHLORIDES

Aside from the melting points, information on the physical properties of sulfonyl chlorides is scarce. Determination of the dipole moments for several sulfonyl chlorides indicates the chlorosulfonyl group is strongly electron attracting.[55] The values reported are benzene-, 4.47, *p*-toluene-, 5.01, and *p*-bromobenzenesulfonyl chloride, 3.23. Timmermans[56] has reported the heats of fusion for several sulfonyl chlorides. The parachor for *p*-toluenesulfonyl chloride is in accord with the presence of two semi-polar double bonds.[57a]

Because of the commercial interest in separating *o*- and *p*-toluenesulfonyl chlorides their melting-point composition curve has been carefully determined.[57b] The eutectic temperature is 1.6° and the eutectic mixture contains 17.5% of the *para* isomer.

REACTIONS OF SULFONYL CHLORIDES

The properties and reactions of benzene-, *p*-toluene-, and the naphthalenesulfonyl chlorides have been investigated in some detail, but the majority of the aromatic sulfonyl chlorides are known only through their melting points and those of the corresponding amides. Little information is therefore available concerning the effect of substituents in the aromatic ring upon the nature or velocity of the reactions which sulfonyl chlorides undergo. Of particular interest would be an investigation of the effect of the presence of groups in both *ortho* positions.

Sulfonyl chlorides not only act as typical acid chlorides but also on occasion may function as chlorinating or oxidizing agents. Their known reactions are therefore numerous. They are comparatively stable compounds and in those of aromatic type only anthraquinone-1-sulfonyl chloride has been reported to decompose on standing; here evolution of sulfur dioxide [58] and formation of 1-chloroanthraquinone occurs.

Hydrolysis. Because of their insolubility sulfonyl chlorides are hydrolyzed very slowly by cold water,[59] *p*-chloro- and *p*-bromobenzenesulfonyl chlorides being entirely unaffected.[60a] To bring about hydrolysis by water alone in any reasonable time requires heating in a sealed tube [60b–f] to 130–140° for several hours although boiling with water eventually brings the reaction to completion.[61] There seems to be no systematic study on record which relates the ease of hydrolysis to structure or to the substituents present in the aromatic ring.

Alkali or concentrated acids aid in effecting hydrolysis. Alcoholic potassium hydroxide [62a] brings about this reaction rapidly. It has been mentioned that the mechanism of the hydrolysis of benzenesulfonyl chloride bears a close resemblance to that of mustard gas.[62b] Warming *p*-bromobenzenesulfonyl chloride to 80° with concentrated sulfuric acid [63a] results in the evolution of hydrogen chloride and treatment of the product with water gives the sulfonic acid.

$$p\text{-BrC}_6\text{H}_4\text{SO}_2\text{Cl} + \text{H}_2\text{SO}_4 \rightarrow p\text{-BrC}_6\text{H}_4\text{SO}_2\text{OSO}_3\text{H} + \text{HCl}$$

$$p\text{-BrC}_6\text{H}_4\text{SO}_2\text{OSO}_3\text{H} + \text{H}_2\text{O} \rightarrow p\text{-BrC}_6\text{H}_4\text{SO}_3\text{H} + \text{H}_2\text{SO}_4$$

Such a reaction also occurs as a step in the conversion of *p*-toluenesulfonyl chloride into toluene-2,4-disulfonic acid.[63b]

With superheated steam *p*-toluenesulfonyl chloride is completely hydrolyzed to toluene and hydrochloric and sulfuric acids.[63c] Several dichloronaphthalenesulfonyl chlorides have been completely hydrolyzed by heating with hydrochloric acid [63d] in a sealed tube above 230°.

Reduction with Metals and Hydrogen. Reduction of sulfonyl chlorides with metals in alkaline or neutral solution yields sulfinates. Calcium in aqueous alkali [64] and zinc dust in water [65, 66] or alcohol [65, 66c, 67] bring this about readily. With zinc in alcohol it is possible to reduce

$$2\text{C}_6\text{H}_5\text{SO}_2\text{Cl} + 2\text{Zn} \rightarrow (\text{C}_6\text{H}_5\text{SO}_2)_2\text{Zn} + \text{ZnCl}_2$$

the sulfonyl chloride group without affecting a nitro group in the same molecule.[68a] Sodium or potassium in toluene converts *p*-toluenesulfonyl chloride[68b] to the disulfone.

Sodium amalgam in benzene or ether, usually in the presence of a small amount of water, has been found[69] to give satisfactory yields of the sodium sulfinate. Here also it has been found possible to leave

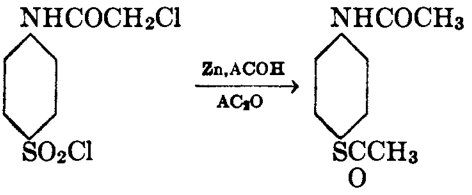
$$C_6H_5SO_2Cl + 2NaHg \rightarrow C_6H_5SO_2Na + NaCl + 2Hg$$

a nitro group unaffected.[70]

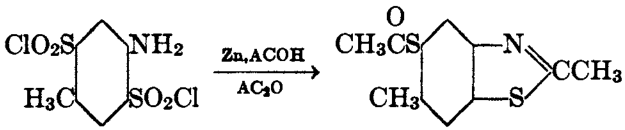
Zinc or iron in acetic acid may be used to reduce benzenesulfonyl chloride to the metal sulfinate[71] but in the presence of hydrochloric or sulfuric acid zinc effects complete reduction[72] to the thiophenol, the sulfinate probably occurring as an intermediate stage.

$$C_6H_5SO_2Cl + 3Zn + 5HCl \rightarrow C_6H_5SH + 2H_2O + 3ZnCl_2$$

Complete reduction to the thiophenol may be brought about with zinc and acetic acid in the presence of acetic anhydride and sodium acetate.[73] The thiophenol is recovered as the acetyl derivative.



Under this treatment an *o*-aminosulfonyl chloride gives a benzothiazole.



Tin or stannous chloride and hydrochloric acid[74] have frequently also been employed. When stannous chloride is used in alcohol at 20° it is possible to stop the reaction at the sulfinic acid stage.[74h] If a nitro group is present in the molecule the final product is an aminothiophenol.[75a,b,c] Iron in a mixture of acetic and hydrochloric acids has been used in one instance[75d] to bring about reduction to the thiophenol. Calcium in acid solution likewise has been shown to yield thiophenol.[64] A complex reaction of somewhat uncertain nature occurs between *p*-toluenesulfonyl chloride and copper in dry pyridine.[76] Several investigations of the electrolytic reduction of sulfonyl chlorides are on record.[77] The thiophenol, disulfide, and sulfinic acid are present in the resulting product. 3-Nitro-4-methylbenzenesulfonyl chloride yields the aminothiocresol.[78]

The catalytic reduction of sulfonyl chlorides in the presence of palladium chloride[79] proceeds rapidly as a reaction of zero order until the sulfinic acid is formed. This is followed by a further slow reduction over a period of ten days to two weeks to give up to a 50% yield of the disulfide. The sulfinic acids from *m*-benzenedisulfonyl chloride and *sym*-benzenetrisulfonyl chloride were not isolated. In the latter reaction some sulfite was formed.

Reduction with Acids and Salts. *m*-Nitrobenzenesulfonyl chloride is reduced by three equivalents of hydrogen iodide in glacial acetic acid to the thiosulfonate.[80] With an excess of hydrogen iodide in

$$2m\text{-}O_2NC_6H_4SO_2Cl + 6HI \rightarrow$$
$$m\text{-}O_2NC_6H_4SO_2SC_6H_4NO_2\text{-}m + 2HCl + 3I_2 + 2H_2O$$

acetic acid at room temperature[81a] or with boiling hydriodic acid[82] the reduction proceeds to the disulfide stage. In the presence of phosphorus less acid is required.[81b] By this procedure *p*-toluenesulfonyl chloride and *m*-carboxybenzenesulfonyl chloride are completely reduced. Benzenesulfonyl chloride is reduced by concentrated aqueous potassium iodide as far as thiophenol.[83] With one equivalent of iodide[84] a mixture of products is obtained including the sulfinate, α-disulfone, and thiosulfonate.

Hydrogen sulfide reduces benzenesulfonyl chloride in cold alcohol to a mixture of thiophenol, diphenyl disulfide, and diphenyl tetrasulfide.[85] Peculiarly enough no reaction takes place in other solvents including methanol, acetic acid, benzene, and water.[86] Sulfides and hydrosulfides reduce sulfonyl chlorides to sulfinic acids or salts of thiosulfonic acids depending upon the reaction conditions. Thus with the minimum amount of sodium sulfide at 100° in water solution[87] the sulfinic acid is formed, whereas with an excess of reagent at lower temperatures

$$2C_6H_5SO_2Cl + Na_2S + H_2O \rightarrow 2C_6H_5SO_2H + 2NaCl + S$$

the product is always the thiosulfonate.[88] With barium hydrosulfide *m*-nitrobenzenesulfonyl chloride has been converted into the thiosul-

$$C_6H_5SO_2Cl + Na_2S \rightarrow C_6H_5SO_2SNa + NaCl$$

fonate[89] but an excess of ammonium hydrosulfide yields the aminothiosulfonate and for 3,5-dinitro-4-methylbenzenesulfonyl chloride[68] the diaminothiocresol is the final product.

Sodium sulfite in neutral or slightly alkaline solution converts sulfonyl chlorides into sulfinates.[90, 91] Sodium arsenite[91] gives similar results.

Reaction with Oxidizing Agents. Heating benzenesulfonyl chloride with lead dioxide at 180° produces chlorobenzene.[92] How generally

$$C_6H_5SO_2Cl + PbO_2 \rightarrow C_6H_5Cl + PbSO_4$$

applicable this reaction may be is not known. *p*-Toluenesulfonyl chloride when treated with lead dioxide and potassium hydroxide undergoes loss of sulfur and oxidation, the products being benzoic and *p*-hydroxybenzoic acids.[93a]

In the presence of sunlight *p*-chlorobenzenesulfonyl chloride is oxidized by atmospheric oxygen with the liberation of free chlorine.[93b] Other chlorides are less affected. The reaction occurs readily in ether and hardly at all in other solvents.

Benzenesulfonyl chloride reacts with sodium peroxide[94] and with potassium permonosulfate[95] to give strong oxidizing agents.

$$2C_6H_5SO_2Cl + Na_2O_2 \rightarrow (C_6H_5SO_2O)_2 + 2NaCl$$

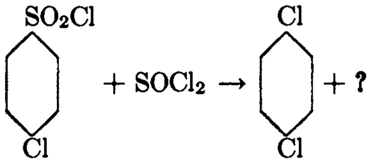
$$C_6H_5SO_2Cl + K_2S_2O_5 \rightarrow C_6H_5SO_2OOSO_3K + KCl$$

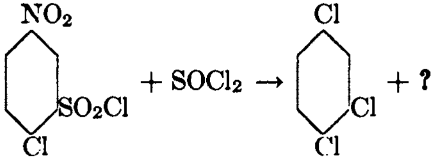
Reaction with Phosphorus Pentachloride and Thionyl Chloride. A very useful method for determining the structure of a sulfonyl chloride is by replacing the chlorosulfonyl group with chlorine by heating the compound with phosphorus pentachloride.

$$ArSO_2Cl + PCl_5 \rightarrow ArCl + POCl_3 + SOCl_2$$

In the benzene series[96] the reaction proceeds at 200–220° while for naphthalene derivatives a somewhat lower temperature usually suffices.[97] This reaction is also of synthetic value in the naphthalene series as it offers a method for obtaining the otherwise inaccessible chlorine derivatives of naphthalene from the readily available sulfonic acids.

Sulfonyl chlorides do not react with thionyl chloride except when the reaction mixtures are heated under pressure to a comparatively high temperature. At 180° benzenesulfonyl chloride and various derivatives which do not contain an alkyl group are converted into chloro compounds with loss of the sulfur.[98]





At 140° *p*-toluenesulfonyl chloride[99] gives chlorination products while

$$p\text{-}CH_3C_6H_4SO_2Cl \xrightarrow{SOCl_2} p\text{-}Cl_2CHC_6H_4Cl$$

at 240° *p*-chlorobenzoyl chloride is formed. Under the same conditions toluene gives benzotrichloride. At 240° *o*-toluenesulfonyl chloride gives a 40% yield of *o*-chlorobenzoyl chloride. *m*-Xylene-4,6-disulfonyl chloride acts similarly[100] to produce 4,6-dichloroisophthaloyl chloride while the *o*-xylenedisulfonyl chloride gives a compound $C_8H_4Cl_6$. *p*-Anisolesulfonyl chloride at 250° is converted into pentachlorophenyl chloromethyl ether.

Reaction with Nitrogen Compounds. The reaction of sulfonyl chlorides with ammonia has already been mentioned. Other nitrogen compounds containing an amino or imino linkage react in the same manner. The formation of sulfonamides in the well-known Hinsberg[101] method for distinguishing between primary, secondary, and tertiary amines is an example of this type of reaction which has been widely studied.[102] Sunlight promotes the reaction with a variety of amines.[102e] Addition products of the sulfonyl chloride and amine have been isolated that cannot be made from the sulfonamide and hydrogen chloride. Occasionally the reaction proceeds abnormally. For example, β-aminoanthraquinone[102d] with *p*-toluenesulfonyl chloride gives, besides the amide, ammonium *p*-toluenesulfonate and a compound $C_{49}H_{28}O_8N_2S$ which could be used as a vat dye. Although tertiary amines apparently do not react with sulfonyl chlorides in aqueous solution the situation is otherwise for anhydrous media. Thus trimethylamine in ether at 0° reacts with benzenesulfonyl chloride[103] as follows.

$$C_6H_5SO_2Cl + 2(CH_3)_3N \rightarrow C_6H_5SO_2N(CH_3)_2 + (CH_3)_4NCl$$

Even at —70° the reaction proceeds at a noticeable rate. *p*-Toluenesulfonyl chloride reacts somewhat more slowly than its lower homolog.

Data on this interesting reaction for other tertiary aliphatic amines are limited to the report that addition compounds are formed.[102e] Dimethylaniline undergoes a complex transformation with *p*-toluenesulfonyl chloride[104] to yield small amounts of crystal violet and bis-(*p*-dimethylaminophenyl)methane, and as the main product the sulfonamide of N-methylaniline. The carbon necessary to form the dyes comes from the liberated methyl group. The sulfone which Michler[105] believed to be formed in the reaction of dimethylaniline with a sulfonyl chloride is actually produced in the presence of aluminum chloride at a low temperature. Benzenesulfonyl and *o*-toluenesulfonyl chlorides

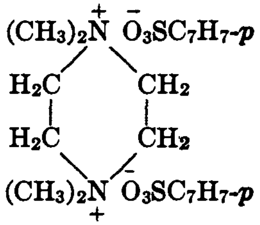
$$C_7H_7SO_2Cl + C_6H_5N(CH_3)_2 \rightarrow C_7H_7SO_2N(CH_3)C_6H_5 + CH_3Cl$$

$$C_7H_7SO_2Cl + 2C_6H_5N(CH_3)_2 \xrightarrow{AlCl_3} C_7H_7SO_2C_6H_4N(CH_3)_2 + C_6H_5N(CH_3)_2HCl$$

react in the same manner as the *p*-toluene derivative. Diethylaniline and methyldiphenylamine yield dyestuffs and probably the sulfonamides. Heterocyclic compounds containing tertiary nitrogen such as pyridine, quinaldine, and acridine[106] form addition compounds. β-Hydroxyethyldimethylamine is converted into a piperazine derivative by *p*-toluenesulfonyl chloride[107] in the presence of sodium carbonate. This reaction results through the intermediate *p*-toluenesulfonate which is a strong alkylating agent.

$$(CH_3)_2NCH_2CH_2OH \xrightarrow[Na_2CO_3]{C_7H_7SO_2Cl}$$

$$(CH_3)_2NCH_2CH_2O_3SC_7H_7 \rightarrow$$



Hydrazine reacts with a sulfonyl chloride to form either the hydrazide or sulfinic acid, depending upon the reaction conditions and the substituents present in the sulfonyl chloride nucleus. Thus one or two moles of benzene- or β-naphthalenesulfonyl chloride react with hydrazine in alkaline solution to form mono and disulfonhydrazides,[108] while sulfonyl chlorides with *ortho* or *para* nitro groups give the sul-

$$C_6H_5SO_2Cl + 2NH_2NH_2 \rightarrow C_6H_5SO_2NHNH_2 + NH_2NH_3Cl$$

$$C_6H_5SO_2Cl + NH_2NHSO_2C_6H_5 + NaOH \rightarrow (C_6H_5SO_2NH)_2 + NaCl + H_2O$$

finic acids at temperatures as low as 35–40° in alcohol-benzene solution.[109] The yields of sulfinic acids are high (80–90%) and the theoretical amount of nitrogen is evolved. Because the temperature at which the sulfinic acid is formed varies with the acid chloride it is possible to separate mixtures of isomeric nitrosulfonyl chlorides [110] by reacting them with hydrazine at a temperature which gives the sulfinic acid of one and the hydrazide of the other. Thus a mixture of *o*- and *p*-nitrobenzenesulfonyl chlorides reacts with hydrazine hydrate in alcohol at 35° to give *o*-nitrobenzenesulfinic acid and *p*-nitrobenzenesulfonhydrazide, the latter crystallizing out. Both compounds are reconverted to sulfonyl chlorides by the action of chlorine. *Ortho-meta* and *meta-para* mixtures behave analogously. 5-Nitro-2-chloro-*p*-toluenesulfonyl chloride and the 6-nitro isomer at 60° give a 55% yield of the 6-nitrosulfonhydrazide and 74% of the 5-nitrosulfinic acid. 2,4-Dinitrobenzenesulfonyl chloride must react with hydrazine at —10° to get the hydrazide, and 4-chloro-2-nitrobenzenesulfonyl chloride could not be converted into this derivative.[111]

$$2o\text{-}O_2NC_6H_4SO_2Cl + 2N_2H_4 \rightarrow 2o\text{-}O_2NC_6H_4SO_2H + N_2 + 2H_2O + N_2H_6Cl_2$$

Derivatives of hydrazine which contain an unsubstituted amino group or one in which a hydrogen has been replaced by alkyl react with sulfonyl chlorides in much the same manner as does hydrazine.[112] *o*-Nitrophenylhydrazine [113] in aqueous alkali with *o*-nitrobenzenesulfonyl chloride yields a cyclic nitrogen compound, but in alcohol the hydrazide is formed.

The reaction of sulfonyl chlorides with hydroxylamine occurs rapidly in alcohol solution.[114] The benzyl ether of hydroxylamine reacts in the same manner.[115] A few ketoximes have been converted into sulfonates by the action of sulfonyl chlorides in alkaline solution [116,117] but more frequently [116,118] the Beckmann rearrangement is induced. *Anti*-benzaldoxime gives a sulfonate but the *syn* form is dehydrated to benzonitrile.[119]

$$C_6H_5SO_2Cl + 2H_2NOH \rightarrow C_6H_5SO_2NHOH + H_2NOH \cdot HCl$$

$$(CH_3)_2C{=}NOH + \beta\text{-}C_{10}H_7SO_2Cl + NaOH \rightarrow (CH_3)_2C{=}NOSO_2C_{10}H_7\text{-}\beta + NaCl + H_2O$$

Unlike the chlorides of carboxylic acids sulfonyl chlorides do not react with diazomethane.[120] This is in accord with the concept that the sulfur-oxygen bonds are semi-polar preventing the formation of the intermediate addition compound possible where a carbonyl group is involved.

Acetamidoxime[121] and phenylacetamidoxime[122] with dry sodium carbonate and chloroform are converted to O-sulfonates. Boiling the

$$CH_3C({=}NOH)NH_2 + C_6H_5SO_2Cl \rightarrow CH_3C({=}NOSO_2C_6H_5)NH_2 + HCl$$

product from benzamidoxime with water[123] gives phenylurea and from *p*-tolamidoxime there results *p*-tolylurea and a compound, $C_6H_5SO_2N_2CC_6H_4CH_3$, whose structure is uncertain.

The oximino groups in a nitrolic acid[124] and in methyl *anti*-benzhydroximate[125] have been esterified with benzenesulfonyl chloride in alkaline solution.

The action of benzenesulfonyl chloride upon urea and a number of related compounds has been briefly mentioned in the literature. At 100° urea[126] is converted into the salt, guanylurea benzenesulfonate. Guanidine[126] yields an amide type of derivative and sodium cyanamide[127] likewise reacts normally. Silver cyanate at 140° converts the

$$C_6H_5SO_2Cl + Na_2NCN \rightarrow C_6H_5SO_2N(Na)CN + NaCl$$

chloride into a mixture of benzenesulfonyl isocyanate and benzenesulfonic anhydride.[128] The action of *p*-toluene-[129] or benzenesulfonyl[130] chloride upon thiourea resembles that of oxidizing agents such as hydrogen peroxide, potassium permanganate, and chlorine. From the benzenesulfonyl chloride reaction were isolated phenyl benzenethiosulfonate ("diphenyl disulfoxide"), dithiourea dichloride, sulfur, and cyanamide.

Reaction with Salts of Organic Acids. Heating benzene- or p-toluenesulfonyl chloride[131] with an excess of dry sodium acetate yields acetic anhydride whereas with the chloride in excess, acetyl chloride is the product. Benzoic acid in pyridine at water-bath temperatures is converted into benzoyl chloride.[132] In a similar manner picric acid

$$C_6H_5SO_2Cl + C_6H_5COOH + C_5H_5N \rightarrow C_6H_5SO_3HNC_5H_5 + C_6H_5COCl$$

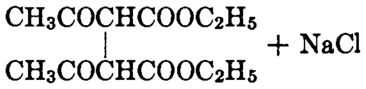
in diethylaniline yields picryl chloride. The silver salts of benzenesulfonic acid[133] and benzenesulfonamide[134] react with benzenesulfonyl chloride to give the anhydride and imide respectively. The sodium salt of the amide yields the same product.[135]

Reaction with Organometallic Compounds. Under the term "organometallic compounds" will be included the sodium derivatives of ethyl acetoacetate and ethyl malonate since the behavior of these toward sulfonyl chlorides is in some respects similar to that of the zinc alkyls and the Grignard reagents. All these metallo compounds act as reducing agents, one of the reaction products being either a sulfinate or sulfoxide.

p-Toluenesulfonyl chloride and ethyl sodioacetoacetate yield a variety of reaction products[136] whose presence is most satisfactorily explained by the following series of equations.

I. $CH_3COCHNaCOOC_2H_5 + C_7H_7SO_2Cl \rightarrow CH_3COCHClCOOC_2H_5 + C_7H_7SO_2Na$

$CH_3COCHClCOOC_2H_5 + CH_3COCHNaCOOC_2H_5 \rightarrow$



$$\begin{array}{l} CH_3COCHCOOC_2H_5 \\ \qquad\quad | \\ CH_3COCHCOOC_2H_5 \end{array} + NaCl$$

II. $CH_3COCHNaCOOC_2H_5 + C_7H_7SO_2Cl \rightarrow CH_3COCH(SO_2C_7H_7)COOC_2H_5 + NaCl$

$CH_3COCH(SO_2C_7H_7)COOC_2H_5 + C_2H_5OH \rightarrow CH_3COOC_2H_5 + C_7H_7SO_2CH_2COOC_2H_5$

The intermediate ethyl *p*-tolylsulfonylacetoacetate was not isolated because of its instability which was demonstrated by its preparation by another method. An alternative source of this intermediate compound would be through the reaction of sodium *p*-toluenesulfinate with ethyl α-chloroacetoacetate.

$$CH_3COCHClCOOC_2H_5 + C_7H_7SO_2Na \rightarrow CH_3COCH(SO_2C_7H_7)COOC_2H_5 + NaCl$$

A more clear-cut chlorination reaction is the one that occurs between the enolate of ethyl isobutyrate and a sulfonyl chloride.[137a]

$$C_6H_5SO_2Cl + Na[(CH_3)_2COOC_2H_5] \rightarrow ClC(CH_3)_2COOC_2H_5 + C_6H_5SO_2Na$$

The main reaction of ethyl sodiomalonate with benzenesulfonyl chloride[137b] is represented by the equations.

$$C_6H_5SO_2Cl + NaCH(COOC_2H_5)_2 \rightarrow C_6H_5SO_2Na + ClCH(COOC_2H_5)_2$$

$$ClCH(COOC_2H_5)_2 + NaCH(COOC_2H_5)_2 \rightarrow (C_2H_5OOC)_2CHCH(COOC_2H_5)_2 + NaCl$$

This reaction is strictly analogous to the reaction with ethyl sodioacetoacetate. As a by-product when two moles of sodium are present there is formed a partial hydrolysis product.[136] This upon acidification decomposes promptly.

$$NaCH(COOC_2H_5)_2 + C_7H_7SO_2Cl + NaOH \rightarrow C_7H_7SO_2CH(COOC_2H_5)COONa + NaCl + C_2H_5OH$$

$$C_7H_7SO_2CH(COOC_2H_5)COOH \rightarrow C_7H_7SO_2CH_2COOC_2H_5 + CO_2$$

Precisely analogous to the chief reaction between sulfonyl chlorides and ethyl sodiomalonate or acetoacetate is that involving a sodium acetylide.[138] Phenyl- and amylchloroacetylene were obtained in 60–65% yields by this method.

$$C_5H_{11}C{\equiv}CNa + C_6H_5SO_2Cl \rightarrow C_5H_{11}C{\equiv}CCl + C_6H_5SO_2Na$$

The reaction of a sulfonyl chloride with a Grignard reagent is complex and the isolation of a good yield of any one product has been achieved rarely. The products obtained when an aromatic Grignard reagent is used are most satisfactorily explained by the accompanying equations.[139] In addition the thiosulfonate is always present and may

$$C_6H_5SO_2Cl + C_6H_5MgBr \rightarrow (C_6H_5)_2SO_2 + MgClBr$$

$$C_6H_5SO_2Cl + C_6H_5MgBr \rightarrow C_6H_5Cl + C_6H_5SO_2MgBr$$

$$C_6H_5SO_2MgBr + C_6H_5MgBr \rightarrow (C_6H_5)_2SO + (MgBr)_2O$$

become the main product. This presumably comes from the sulfinate. Small amounts of other substances also have been identified. Phenyl

$$3C_6H_5SO_2MgBr \rightarrow C_6H_5SO_2SC_6H_5 + C_6H_5SO_3MgBr + (MgBr)_2O$$

sulfoxide is reduced slowly by the Grignard reagent and the small amount of phenyl sulfide probably arises from this source.

The products isolated from the action of *p*-toluenesulfonyl chloride with methylmagnesium iodide and ethylmagnesium bromide [139b] do not account for more than a minor portion of the reactants. Thus the methyl Grignard reagent gives a trace of *p*-tolyl methyl sulfide and a considerable quantity of *p*-tolyl *p*-toluenethiosulfonate. Presumably methyl chloride is also produced but this was not isolated. From 65 g. of the sulfonyl chloride ethylmagnesium bromide gave 15 g. of *p*-tolyl ethyl sulfide and a trace of *p*-tolyl *p*-toluenethiosulfonate besides magnesium *p*-toluenesulfonate.

Benzenesulfonyl chloride reacts with diethylzinc to give zinc benzenesulfinate and probably ethyl chloride.[140] When ethylzinc iodide is employed [141] both the sulfinate and phenyl ethyl sulfone are isolated from the reaction mixture. Diphenylmercury reacts at 160° with benzene- or *p*-toluenesulfonyl chloride to give a small yield of the sulfone.[142]

$$(C_6H_5)_2Hg + C_6H_5SO_2Cl \rightarrow (C_6H_5)_2SO_2 + C_6H_5HgCl$$

Reaction with Alcohols. Since the discovery that alkyl sulfonates are good alkylating agents (see p. 528) the reaction of sulfonyl chlorides with alcohols of various types has been investigated in detail. Methyl, ethyl, and *n*-propyl alcohols react slowly with a sulfonyl chloride at room temperature [143] or below, several days elapsing before the chloride has disappeared. To prepare ethyl *p*-toluenesulfonate in this manner requires six to seven days at 30°. If benzenesulfonyl chloride is boiled with excess alcohol for several hours no ester is isolated,[144] the products being ethyl chloride, ethyl ether, and the sulfonic acid.

$$C_6H_5SO_2Cl + C_2H_5OH \rightarrow C_6H_5SO_3C_2H_5 + HCl$$

$$C_6H_5SO_3C_2H_5 + C_2H_5OH \rightarrow C_6H_5SO_3H + (C_2H_5)_2O$$

$$C_6H_5SO_3C_2H_5 + HCl \rightarrow C_2H_5Cl + C_6H_5SO_3H$$

$$C_6H_5SO_2Cl + C_2H_5OH \rightarrow C_2H_5Cl + C_6H_5SO_3H$$

There is no proof that the last-written equation corresponds to a reaction which actually occurs but it seems plausible that part of the ethyl chloride may arise in this manner. It is known that phenylmethylcarbinol with *p*-toluenesulfonyl chloride in pyridine yields only α-phenylethyl chloride whereas in the absence of a base, styrene is formed. If the alcohol is not present in large excess refluxing the mixture yields some ester. It is probable that the reported formation of alkyl sulfonates by heating the acid chloride with an alcohol [145] was because of the use of the equivalent amount of alcohol or a short reaction time. *n*-Propyl and *n*-butyl *p*-toluenesulfonate have been prepared in 25–30% yields by refluxing the acid chloride with a 10% excess of the alcohol.[146] If dry air is passed through the reaction mixture containing *p*-toluenesulfonyl chloride and *n*-propyl alcohol at 100–125° so that the hydrogen chloride is removed as fast as it is formed,[147] about 70% of the ester and 5% of the ether are obtained. A small amount of sodium carbonate was added to neutralize any *p*-toluenesulfonic acid produced in side reactions. Probably ethyl chloride is a by-product in this method of preparation, but it was not reported. If benzenesulfonyl chloride and methanol are heated in a sealed tube to 160° methyl chloride and benzenesulfonic acid are the sole products.[144] One would expect that secondary and tertiary alcohols may be more readily converted to chlorides than are the primary but no evidence on this point is available. The presence of a *beta* chlorine apparently reduces side reactions as refluxing *p*-toluenesulfonyl chloride with excess ethylene chlorohydrin yields the ester [148] rather than the ether and ethylene chloride. The cyano group has a similar effect as β-cyanoethyl *p*-toluenesulfonate is formed in 65% yield by heating the reactants in boiling xylene for several hours.[149]

Addition of alkali to a sulfonyl chloride-alcohol reaction mixture greatly accelerates esterification, high yields of esters being obtainable [150] at temperatures in the range 0–15°. In some instances more satisfactory results are obtained by carrying out the reaction in ether solution, either alkali being added to the anhydrous reaction mixture [151] or the sulfonyl chloride added to an ether solution of the sodium alkoxide.[130d, 152] Benzene also has been used [153] as a solvent for the reaction. Alternatively the reaction may be brought about by addition of a tertiary amine. Benzenesulfonyl chloride has been converted into the ethyl ester in the presence of trimethylamine [154] and many alkyl sulfonates have been prepared in procedures involving pyridine as the acceptor for the hydrogen chloride.[153, 155] "Tosylation" [156] of sugar derivatives is conveniently carried out in the presence of pyridine. A practical application of the esterification of cellulose with *p*-toluenesulfonyl chloride is the immunization of cotton and rayons to direct, sulfur, and vat dyes. This is of possible use in design dyeing.[157]

Reaction with Phenols. The reaction of sulfonyl chlorides with phenols proceeds in one or the other of two ways depending upon the substituents present in the phenol nucleus and the reaction conditions. If the reaction is carried out in the presence of an alkali hydroxide or carbonate only esters are produced while in the presence of diethylaniline or pyridine phenols in which two or more nitro groups are present may be converted into chlorides.

$$C_6H_5ONa + p\text{-}CH_3C_6H_5SO_2Cl \rightarrow C_6H_5OSO_2C_6H_4CH_3\text{-}p + NaCl$$

$$(O_2N)_3C_6H_2OH + p\text{-}CH_3C_6H_4SO_2Cl + C_6H_5N(C_2H_5)_2 \rightarrow$$

$$(O_2N)_3C_6H_2Cl + CH_3C_6H_4SO_3NH(C_6H_5)(C_2H_5)_2$$

Picric acid does not react with *p*-toluenesulfonyl chloride in the presence of a strong base.

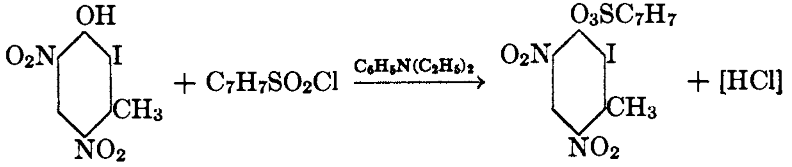
Aside from this behavior of nitrophenols the esterification of phenols by sulfonyl chlorides is singularly free from side reactions under a variety of conditions. It has been reported that β-naphthol reacts with *p*-toluenesulfonyl chloride [158] when these are heated together at 140° but esterification occurs more readily in the presence of some condensing agent. Benzenesulfonyl chloride is said to react with phenol [159] at 60° in the presence of zinc but there may be some doubt as to the usefulness of this agent in bringing about such reactions. A procedure of more general value consists in treating a solution of the phenol in aqueous alkali [160] or sodium carbonate [161] with the sulfonyl chloride; the latter if a solid may be dissolved in benzene or ether. Using alcohol for a reaction solvent [162] confers the advantage of a homogeneous reaction mixture and is of value for high-molecular-weight phenols such as 2,5-diphenylphenol.[163] Sodium phenoxide has been observed [164a] to react readily in benzene solution. The silver salt of 2-nitro-4-methylphenol [164b] behaves abnormally with *p*-toluenesulfonyl chloride, a sulfur-free compound with the composition $C_{14}H_{13}O_5N$ being isolated from the reaction mixture.

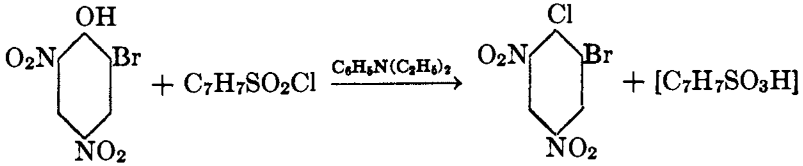
The sodium salt of *o*-aminophenol with benzenesulfonyl chloride gives an 82% yield of the sulfonate but with *o*-aminophenol itself the anilide results.[164c] *o*-Hydroxybenzanilide readily reacts with benzenesulfonyl chloride without rearrangement such as occurs with acyl chlorides.

As with the alcohols, esterification of phenols by sulfonyl chlorides proceeds readily in the presence of dimethylaniline,[164d] diethylaniline,[165] or pyridine.[161d, 166] The same effect is obtained by having the dimethylamino and phenolic groups in the same molecule.[167] The conversion of di- and trinitrophenols into chlorides by the action of

$$p\text{-}C_7H_7SO_2Cl + p\text{-}HOC_6H_4N(CH_3)_2 \rightarrow p\text{-}C_7H_7SO_3C_6H_4N(CH_3)_2HCl$$

p-toluenesulfonyl chloride in the presence of diethylaniline [161e, 165a, 168] has been found to be a general reaction. It is necessary for the two nitro groups to be *ortho* or in the *ortho* and *para* positions; a dinitrophenol with a methyl group meta yields the ester.[169a] Picramic acid [169b] with two moles of *p*-toluenesulfonyl chloride in pyridine gives as the final product anhydro-2,4-dinitro-6-*p*-toluenesulfonamidophenylpyridinium hydroxide which with nitric or hydrochloric acid gives the corresponding salt. The presence of an iodine atom *ortho* to hydroxyl prevents replacement of the hydroxyl but bromine does not.





Both 2,4-dinitrophenol [166a] and the 2,6-isomer [170a] yield mixtures of the ester and chloride. Dinitro-*o*-cresol reacts similarly.[170b] If one of the nitro groups of a dinitrophenol is replaced by a cyano, acetyl, or benzoyl group ester formation greatly dominates or is the sole reaction.[171a] Thus 4-cyano-2-nitrophenol yields only about 5% of the 4-chloro-3-nitrobenzonitrile when treated with *p*-toluenesulfonyl chloride in the presence of diethylaniline, the main product being the *p*-toluenesulfonate. 2-Nitro-6-cyano-4-methylphenol and 3-nitro-4-hydroxy-5-methoxybenzonitrile yield only the esters while 4,6-dinitro-2-methoxyphenol gives also a little 2-chloro-3,5-dinitroanisole. It has been suggested[171b] that the formation of the chlorine compounds is a secondary reaction, occurring as the final stage in the series of changes indicated.

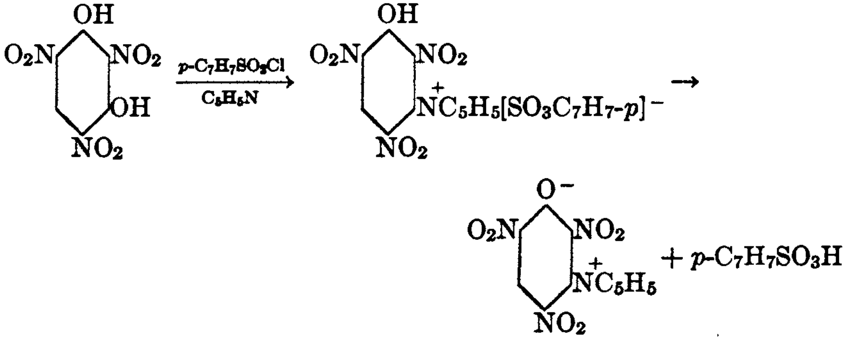
$$\mathrm{ArOH} + p\text{-}\mathrm{C_7H_7SO_2Cl} \rightarrow \mathrm{ArOSO_2C_7H_7} + \mathrm{HCl}$$

$$\mathrm{ArOSO_2C_7H_7} + \mathrm{C_6H_5N(C_2H_5)_2} \rightarrow \mathrm{[C_6H_5N(C_2H_5)_2Ar]O_3SC_7H_7}$$

$$\mathrm{[C_6H_5N(C_2H_5)_2Ar]O_3SC_7H_7} + \mathrm{HCl} \rightarrow \mathrm{[C_6H_5N(C_2H_5)_2Ar]Cl} + \mathrm{C_7H_7SO_3H}$$

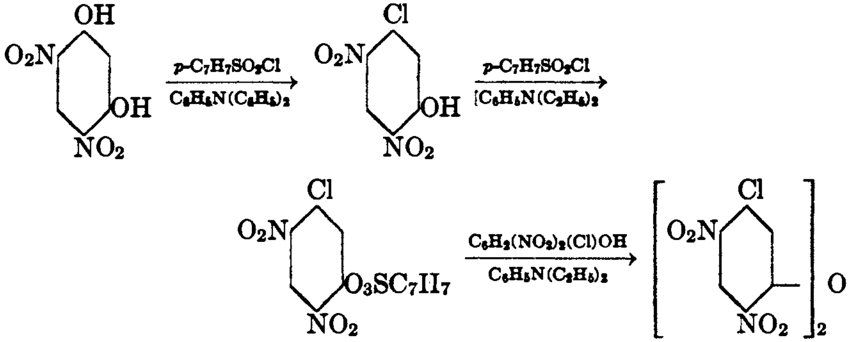
$$\mathrm{[C_6H_5N(C_2H_5)_2Ar]Cl} \rightarrow \mathrm{C_6H_5N(C_2H_5)_2} + \mathrm{ArCl}$$

This mechanism is in accord with the ready decomposition of the addition compound of 2,4-dinitro-6-methylphenyl *p*-toluenesulfonate and pyridine with dilute hydrochloric acid to give the dinitrochlorotoluene while the ester alone undergoes simple hydrolysis under the same conditions. Polynitrophenols which give only sulfonates under usual conditions can be converted into chlorides by first allowing the sulfonates to react with pyridine, then decomposing the pyridinium compound with hydrochloric acid. Picric acid and *p*-toluenesulfonyl chloride in pyridine at ordinary temperatures[172] yield picryl pyridinium *p*-toluenesulfonate indicating that under these conditions the ester is the primary product. On the other hand, 2,4,6-trinitroresorcinol (styphnic acid) yields 2,4,6-trinitro-3-hydroxyphenylpyridinium betaine.[168d]

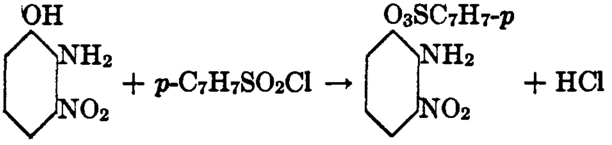


3-Hydroxy-2,4,6-trinitrodiphenylamine gives the pyridinium *p*-toluenesulfonate (rather than a pyridine betaine) which decomposes when treated with 2 *N* hydrochloric acid to form the chlorotrinitrodiphenylamine.

When 4,6-dinitroresorcinol is treated with *p*-toluenesulfonyl chloride in diethylaniline there results a mixture of 2,4,2′,4′-tetranitro-5,5′-dichlorodiphenyl ether and 1,3-dinitro-4,6-dichlorobenzene.



Reaction with Nitroamines. Aromatic amines containing nitro groups behave anomalously toward *p*-toluenesulfonyl chloride in that the formation of sulfonamides is frequently difficult while the preparation of disubstituted compounds is relatively easy.[173] Thus equimolecular amounts of *o*-nitroaniline and *m*-nitrobenzenesulfonyl chloride in pyridine give a mixture of mono- and disulfonamides. In the action of *p*-toluenesulfonyl chloride upon nitroaminophenols the amino group reacts first unless it is protected by two *ortho* substituents.



Reaction with Thiols. The reaction of a sulfonyl chloride with an aromatic thiol in alkaline solution results in an oxidation-reduction reaction rather than esterification. Benzenesulfonyl chloride reacts with an alkali [174] or lead [175] salt of thiophenol according to the equation.

$$2C_6H_5SNa + C_6H_5SO_2Cl \rightarrow (C_6H_5S)_2 + C_6H_5SO_2Na + NaCl$$

p-Toluenesulfonyl chloride reacts in the same manner.[176] An aliphatic thiol may react in either of the two ways, depending upon the ratios of the reactants.[177]

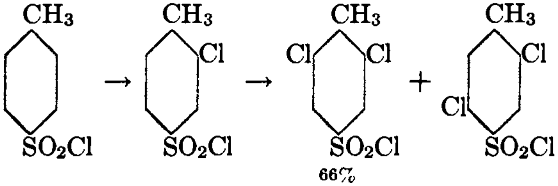
$$p\text{-}C_7H_7SO_2Cl + C_5H_{11}SNa \rightarrow p\text{-}C_7H_7SO_2SC_5H_{11} + NaCl$$

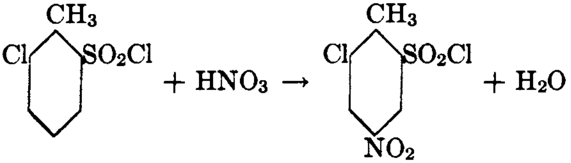
$$p\text{-}C_7H_7SO_2SC_5H_{11} + C_5H_{11}SNa \rightarrow (C_5H_{11}S)_2 + p\text{-}C_7H_7SO_2Na$$

Both the oxidized and reduced forms of glutathione reduce β-napthalenesulfonyl chloride to the sulfinic acid in alkaline solution.[178]

Substitution Reactions. Halogenation and nitration of sulfonyl chlorides may be effected without modifying the sulfonyl chloride group. As has already been mentioned treatment with sulfuric acid results in loss of the chlorine as hydrogen chloride.

Chlorination of *p*-toluenesulfonyl chloride[179] at 70–80°, preferably in the presence of antimony trichloride[180] results in substitution in the ring. In the absence of a catalyst[4b] side-chain chlorination can be brought about. A yield of 62% of ω-chloro-*p*-toluenesulfonyl chloride has been reported when the halogenation was conducted at 160–210°. One product obtained from chlorination of the *o*-toluenesulfonyl chloride was the sultone. In the nitration of 3-chloro-4-methylbenzenesulfonyl chloride the *para* directive influence of the chlorine is three times as great as the *ortho* directive influence of methyl and the *meta* influence of the sulfonyl chloride group combined whereas in 3-chloro-2-methylbenzenesulfonyl chloride the chlorine has a slightly smaller effect than the other two groups. In this latter nitration the sulfonyl chloride group exerts a greater effect than a nitro group in the same location. Nitration of 4-chloro-3-methylbenzenesulfonyl chloride gives a 90% yield of the 5-nitro compound.[181]





A number of substituted nitronaphthalenesulfonyl chlorides have been obtained by nitration reactions.[182]

Sulfone Formation. Sulfonyl chlorides react readily with aromatic hydrocarbons and some of their derivatives in the presence of aluminum chloride to give sulfones.[183] The presence of a substituent in the sulfonyl chloride nucleus has considerable effect upon the rate at which the reaction occurs,[184] the methyl group increasing the rate and halogen and nitro groups decreasing it. In the following series the groups are placed in the order in which the corresponding sulfonyl chlorides react.

$$p\text{-CH}_3 > o\text{-CH}_3 > m\text{-CH}_3 > \text{H} > p\text{-Cl} > o\text{-Cl} > m\text{-Cl} > m\text{-NO}_2 > o\text{-NO}_2 > p\text{-NO}_2$$

SULFONYL BROMIDES AND IODIDES

In contrast to the sulfonyl chlorides sulfonyl bromides and particularly the iodides have been investigated but little.

Sulfonyl bromides have been prepared by three methods. Treating an aqueous solution of an alkali sulfinate with bromine water[185] precipitates the sulfonyl bromide. *p*-Thiocresol, 2,4,6-tribromothiophenol,

$$\text{C}_6\text{H}_5\text{SO}_2\text{Na} + \text{Br}_2 \rightarrow \text{C}_6\text{H}_5\text{SO}_2\text{Br} + \text{NaBr}$$

and dithiohydroquinone have been converted into sulfonyl bromides by the action of bromine in acetic acid or water.[186]

$$p\text{-CH}_3\text{C}_6\text{H}_4\text{SH} + 3\text{Br}_2 + 2\text{H}_2\text{O} \rightarrow p\text{-CH}_3\text{C}_6\text{H}_4\text{SO}_2\text{Br} + 5\text{HBr}$$

By the action of one molecule of phosphorus pentabromide upon an alkali sulfonate the sulfonyl bromide[187] results in varying yield. An excess of phosphorus pentabromide converts the sulfonate into a disulfide.[186b] This may be accounted for as follows.

$$\text{PBr}_5 \rightleftharpoons \text{PBr}_3 + \text{Br}_2$$

$$2\text{ArSO}_2\text{Br} + 5\text{PBr}_3 \rightarrow \text{ArSSAr} + 4\text{POBr}_3 + \text{PBr}_5$$

It had previously been reported[187f, h] that brominated α-naphthalenesulfonyl bromides were converted into dibromonaphthalenes by the action of phosphorus pentabromide. It has been mentioned earlier (see p. 500) that sulfonyl chlorides of the naphthalene series are more readily converted into chloro- compounds than are benzene derivatives. In the work of Kohlhase[186b] phosphorus tribromide was found to act as a reducing agent towards α-naphthalenesulfonyl bromide but the effect of the pentabromide was not reported. A remarkable reaction was reported by Gessner[188] who found that phosphorus pentachloride converts sodium 4-bromonaphthalenesulfonate into 4-chloronaphthalenesulfonyl bromide.

The sulfonyl bromides are oils or low-melting solids. The crystallographic properties have been determined for a number of halogenated benzenesulfonyl bromides.[189] The chemical properties of the sulfonyl bromides are undoubtedly very similar to those of the chlorides although there is little evidence on this point. *p*-Toluenesulfonyl bromide has been reduced to *p*-thiocresol.[186a] *p*-Bromobenzenesulfonyl bromide reacts with aluminum bromide in carbon disulfide to give a sulfinate[187i] and bromine. Bromine also is evolved when a sulfonyl

$$p\text{-}BrC_6H_4SO_2Br + AlBr_3 \rightarrow p\text{-}BrC_6H_4SO_2AlBr_2 + Br_2$$

bromide is heated with sulfuric acid. Sodium phenylacetylide reacts with a sulfonyl bromide to yield phenylbromoacetylene.[188b]

Sulfonyl iodides have been prepared in only one way, by the action of iodine upon an alkali sulfinate in alcohol solution.[190]

$$C_6H_5SO_2Na + I_2 \rightarrow C_6H_5SO_2I + NaI$$

In contrast to the chlorides, a sulfonyl iodide is converted by aqueous potassium hydroxide into the potassium sulfinate and potassium iodate.[190a,c] Shaking with silver powder in an anhydrous solvent

$$3C_6H_5SO_2I + 6KOH \rightarrow 3C_6H_5SO_2K + 2KI + KIO_3 + 3H_2O$$

yields the sulfonic acid and thiosulfonate[190c] instead of the anticipated α-disulfone. Diethylzinc yields the zinc sulfinate.[190a]

$$2C_6H_5SO_2I + (C_2H_5)_2Zn \rightarrow (C_6H_5SO_2)_2Zn + 2C_2H_5I$$

p-Toluenesulfonyl iodide reacts slowly with di-*p*-tolylmercury to give *p*-tolyl sulfone.[191] Some mercuric iodide was formed indicating

$$C_7H_7SO_2I + (C_7H_7)_2Hg \rightarrow (C_7H_7)_2SO_2 + C_7H_7HgI$$

that both *p*-tolyl groups reacted.

$$C_7H_7HgI + C_7H_7SO_2I \rightarrow (C_7H_7)_2SO_2 + HgI_2$$

Sodium acetylides react as they do with sulfonyl chlorides and bromides to yield iodoacetylenes.[188b]

$$C_6H_5C{\equiv}CNa + C_6H_5SO_2I \rightarrow C_6H_5C{\equiv}CI + C_6H_5SO_2Na$$

ALKYL SULFONATES

Preparation and Physical Properties. The preparation of alkyl sulfonates by the action of sulfonyl chlorides upon alcohols, preferably in the presence of sodium or potassium hydroxide or of pyridine below 15°, has been described previously (see p. 507). Either of these procedures usually gives 70–90% yields. Several other methods of considerably less usefulness have been described in the literature. Heating the silver salt of a sulfonic acid with methyl or ethyl iodide converts various substituted naphthalenesulfonic acids into the corresponding esters. A related method consists in heating an alkali sul-

$$ArSO_3Ag + CH_3I \rightarrow ArSO_3CH_3 + AgI$$

fonate to 150–160° with methyl or ethyl sulfate. Oxidation of an al-

$$ArSO_3Na + (CH_3)_2SO_4 \rightarrow ArSO_3CH_3 + CH_3NaSO_4$$

kyl sulfinate in acetic acid or benzene by adding an aqueous solution of potassium permanganate or hydrogen peroxide gives the sulfonate in fair yield.

$$3ArSO_2C_2H_5 + 2KMnO_4 + 2CH_3COOH \rightarrow 3ArSO_3C_2H_5 + 2MnO_2 + 2CH_3COOK + H_2O$$

Compounds which were believed to be esters of sulfonic acids have been obtained by the action of diazomethane upon some aminoazobenzenesulfonic acids.[1a] The strong alkylating action of alkyl sulfonates suggests that these are actually quaternary ammonium salts rather than esters, however. Attempts to prepare esters of sulfanilic acid resulted in failure.[1c] *p*-Toluenesulfonates of desoxycorticosterone and similar ketols [1b] have been made from the corresponding diazo ketones and *p*-toluenesulfonic acid.

Heating phenol with methyl sulfate results in a complex series of reactions which produces a fair yield of methyl *p*-anisolesulfonate.[2]

$$C_6H_5OH + (CH_3)_2SO_4 \rightarrow p\text{-}CH_3OC_6H_4SO_3CH_3 + H_2O$$

One example of obtaining an alkyl sulfonate by the action of a sulfonic anhydride on an alcohol is on record.[3a] Cyclohexene oxide adds

$$(C_6H_5SO_2)_2O + C_2H_5OH \rightarrow C_6H_5SO_3C_2H_5 + C_6H_5SO_3H$$

p-toluenesulfonic acid in ether [3b] to give the monosulfonate of the *trans* glycol in 90% yield. The reaction is not satisfactory, however, with cyclopentene oxide. It has been claimed in the patent literature [4]

$$C_6H_{10}O + p\text{-}C_7H_7SO_3H \rightarrow C_6H_{10}(OH)O_3SC_7H_7\text{-}p$$

that alkyl sulfonates may be obtained by the action of a sulfonic acid with olefins. No pure products were isolated, however. No tertiary alkyl sulfonate has been prepared by any of the available methods.

In Table XVIII are listed the alkyl sulfonates together with the methods by which they have been made and their common physical properties. In the second column under Method of Preparation I refers to the reaction between a sulfonyl chloride and an alcohol, II to the reaction of a silver sulfonate with an alkyl iodide, III to the sodium sulfonate-alkyl sulfate reaction, IV to oxidation of a sulfinate by potassium permanganate, and V to miscellaneous methods.

TABLE XVIII

ALKYL SULFONATES

Formula	Method of Preparation	M.P., °C.	B.P., °C. (mm.)
$C_6H_5SO_3CH_3$	I,$^{1, 2, 23, 124, 129}$ III$^{3, 4}$	....	154 (20)
$C_6H_5SO_3C_2H_5$	I,$^{1, 2, 5, 7 39}$ III,^{6} IV^{10}	....	156 (15)
$C_6H_5SO_3C_3H_7$-*n*	I$^{1, 2, 82}$	....	162 (15)
$C_6H_5SO_3C_3H_7$-*iso*	I^{32}	....	....
$C_6H_5SO_3CH_2CH{=}CH_2$	I$^{26, 32, 38}$	....	Dec. 186
$C_6H_5SO_3CH_2CH_2Cl$	I$^{26, 36}$	....	184 (9)
$C_6H_5SO_3CH_2CH_2Br$	I$^{26, 36}$	....	186 (16)
$C_6H_5SO_3CH_2CH_2OC_2H_5$	I^{123}	....	180–190 (10)
$C_6H_5SO_3CH(CH_2Cl)_2$	I$^{26, 36}$	50	200–205 (20)
$C_6H_5SO_3C_{10}H_{19}$ (menthyl)	I$^{8, 9, 100}$	80	Dec.
$C_6H_5SO_3CH_2C_6H_5$	I$^{32, 38}$	59–60	Dec. 125
$C_6H_5SO_3CH(C_6H_5)COC_6H_6$	I^{38}	99–100	....
$(C_6H_5SO_3CH_2)_2$	I^{38}	49–50	190 (1)
p-$ClC_6H_4SO_3CH_3$	I^{1}	50.5	165–166 (15)
p-$ClC_6H_4SO_3C_2H_6$	I^{1}	25–26	171–172 (15)
p-$BrC_6H_4SO_3CH_3$	I^{1}	60	176 (15)
p-$BrC_6H_4SO_8C_2H_5$	I^{1}	39.5	181–182 (15)
p-$BrC_6H_4SO_3C_{10}H_{21}$-*n*	I^{11}	43–44	....
p-$BrC_6H_4SO_3C_{12}H_{25}$-*n*	I^{11}	49	....
p-$BrC_6H_4SO_3C_{14}H_{29}$-*n*	I^{11}	51.5	....
p-$BrC_6H_4SO_3C_{16}H_{33}$-*n*	I^{11}	60	....
p-$BrC_6H_4SO_3C_{18}H_{37}$-*n*	I^{11}	64–65	....
p-$IC_6H_4SO_3CH_3$	I^{12}	74	....
p-$IC_6H_4SO_3C_2H_5$	I^{17}	51	....
2,5-$Cl_2C_6H_3SO_3CH_3$	I^{18}	37	....
2,5-$Cl_2C_6H_3SO_3C_2H_6$	I^{13}	73.5	....
2,5-$Cl_2C_6H_3SO_3C_3H_7$-*n*	I^{18}	45	....
2,5-$Cl_2C_6H_3SO_3C_4H_9$-*n*	I^{13}	31	....
2,5-$Cl_2C_6H_3SO_3C_6H_{10}OH$-2-*trans*	V^{120}	134	....
2,5-$Br_2C_6H_3SO_3CH_3$	I^{14}	63	....
2,5-$Cl_2C_6H_3SO_3C_6H_{10}OOCCH_3$-2-*trans*	V^{120}	170	....
2,5-$IClC_6H_3SO_3C_2H_6$	I^{14}	87	....
2,3-$I_2C_6H_3SO_3CH_3$	I^{18}	101	....
2,3-$I_2C_6H_3SO_3C_2H_5$	I^{15}	77–78	....
2,4-$I_2C_6H_3SO_3CH_3$	I^{16}	78	....
2,4-$I_2C_6H_8SO_3C_2H_6$	I^{18}	57	....
2,5-$I_2C_6H_3SO_3CH_3$	I^{13}	106	....
2,5-$I_2C_6H_3SO_3C_2H_5$	I$^{18, 18}$	120.5	....
3,4-$I_2C_6H_3SO_3CH_3$	I^{16}	93	....
3,4-$I_2C_6H_3SO_3C_2H_5$	I$^{16, 18}$	82.5	....
3,5-$I_2C_6H_3SO_3CH_3$	I^{16}	95	....
3,5-$I_2C_6H_3SO_3C_2H_6$	I^{16}	112	....
2,3,5-$I_3C_6H_2SO_3CH_3$	I^{16}	137	....

TABLE XVIII (*Continued*)

Formula	Method of Preparation	M.P., °C.	B.P., °C. (mm.)
2,3,5-$I_3C_6H_2SO_3C_2H_5$	I[16, 18]	110	....
2,4,5-$I_3C_6H_2SO_3CH_3$	I[16]	166	....
2,4,5-$I_3C_6H_2SO_3C_2H_5$	I[16]	155–156	....
3,4,5-$I_3C_6H_2SO_3CH_3$	I[18]	157	....
3,4,5-$I_3C_6H_2SO_3C_2H_5$	I[16]	143	....
m-$C_2H_5OC_6H_4SO_3C_2H_5$	I[76]	Oil	Dec.
p-$HOC_6H_4SO_3CH_3$	V[118]	97	....
p-$HOC_6H_4SO_3C_2H_5$	H[77, 78]	Oil	Dec.
p-$CH_3OC_6H_4SO_3CH_3$	V[118]	30	160 (3)
p-$C_6H_5COOC_6H_4SO_8CH_3$	V[118]	104	....
p-$CH_3COOC_6H_4SO_3CH_3$	V[118]	71	....
3,5,4-$Br_2(HO)C_6H_2SO_3CH_3$	I[79]	196–197	....
3,5,4-$Br_2(HO)C_6H_2SO_3C_2H_5$	I[79]	146–147	....
4,3-$HO(CH_3OCOO)C_6H_3SO_3CH_3$	V[118]	65	....
4,3-$CH_3COO(CH_3OCOO)C_6H_3$-SO_3CH_3	V[118]	68	....
o-$O_2NC_6H_4SO_3C_2H_5$	I[39]	15	163–164 (0.0-)
m-$O_2NC_6H_4SO_3C_2H_5$	I[19, 39]	42	....
p-$O_2NC_6H_4SO_3C_2H_5$	I[39, 109]	92	....
o-$O_2NC_6H_4SO_3C_{10}H_{19}$ (*l*-menthyl)	I[45]	66	....
m-$O_2NC_6H_4SO_3C_{10}H_{19}$	I[45]	80	....
p-$O_2NC_6H_4SO_3C_{10}H_{19}$	I[45, 109]	70.5, 72	....
3,4-$O_2N(CH_3O)C_6H_3SO_3CH_3$	I[80]	83	....
o-$(CH_3)_2NC_6H_4SO_3CH_3$	III[28]	....	....
m-$(CH_3)_2NC_6H_4SO_3CH_3$	III[28]	....	....
p-$(CH_3)_2NC_6H_4SO_3CH_3$	III[28]	....	....
p-$CH_3NHC_6H_4N_2C_6H_4SO_3CH_3$	III[42]	113 (dec.)	....
p-$(CH_3)_2NC_6H_4N_2C_6H_4SO_3CH_3$	III[42]	125	....
o-$CH_3C_6H_4SO_3C_{10}H_{19}$	I[45]	78	....
p-Toluenesulfonates, Alkyl or Alkylene Group			
CH_3-	I[20, 23, 105]	28	292 (760)
C_2H_6-	I,[1, 20, 21, 23, 24, 25, 27, 116] IV[10]	32–33	173 (15)
$ClCH_2CH_2$-	I[29, 30, 37, 106]	....	210 (21)
$BrCH_2CH_2$-	I[104]	....	203 (5)
n-C_3H_7-	I[31, 32, 34]	....	154–156 (3)
$ClCH_2CH_2CH_2$-	I[30, 33, 107]	....	188–192 (5)
iso-C_3H_7-	I[33]	....	....
$(ClCH_2)_2CH$-	I[35]	52–53	180–210 (13)
n-C_4H_9-	I[11, 31, 34, 106]	....	169 (4)
iso-C_4H_9-	I[31]	....	163–165 (3)
sec-C_4H_9-	I,[31, 43] IV[43]	....	95 (0.1)
n-C_5H_{11}-	I[31]	....	169–170 (3)
iso-C_5H_{11}-	I[112]	....	156 (0.06)
$(C_2H_5)_2CH$-	I[98]	32–33	....

TABLE XVIII (*Continued*)

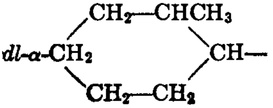
Formula	Method of Preparation	M.P., °C.	B.P., °C. (mm.)
p-Toluenesulfonates, Alkyl or Alkylene Group (Continued)			
n-C_6H_{13}-	I[112]		< 145–150 (0.05)
n-$C_6H_{13}CH(CH_3)$-	I[43]		
n-$C_{12}H_{25}$-	I[11]	30	
n-$C_{14}H_{29}$-	I[11]	35	
n-$C_{16}H_{33}$-	I[11]	49	
n-$C_{18}H_{37}$-	I[11]	56	
$HOCH_2CH_2$-	I[113]	Oil	
$C_2H_5OCH_2CH_2$-	I[113]		186–187 (3)
$ClCH_2CH_2OCH_2CH_2$-	I[119]	Oil	
n-$C_4H_9OCH_2CH_2$-	I[119]	Oil	
$C_6H_5OCH_2CH_2$-	I[97, 119]	75, 80	
m-$ClC_6H_4OCH_2CH_2$-	I[97]	57	
p-$ClC_6H_4OCH_2CH_2$-	I[97]	79	
β-$C_{10}H_7OCH_2CH_2$-	I[97]	90	
$C_6H_5CH_2OCH_2CH_2$-	I[125, 126]	45	
$C_6H_5COOCH_2CH_2$-	I[113]	74–75	
C_2H_4- di	I[113]	126	
$CH_3CHOHCH_2$-	I[128]	46	
$C_6H_5CH_2OCH_2CH(CH_3)$-	I[126]	49	
$C_6H_5CH_2O(CH_2)_3$-	I[125, 126]	37	
$C_6H_5CH_2OC(CH_3)_2CH_2$-	I[128]	47	
$HOCH_2CHOHCH_2$-	I[127]	63–64	
$(C_6H_5CH_2OCH_2)_2CH$-	I[125, 126]	"Amorphous"	
$CH_2{=}CHCH_2$-	I[31]		148–150 (3)
$CH_3OOCCH(CH_3)$-	I[102]		
$(+)C_2H_5OOCCH(CH_3)$-	IV[121]		138 (0.1)
$ClCOCH(CH_3)$-	V[106]		
$NH_2COCH(CH_3)$-	V[106]		
$(CH_3)_2NCOCH(CH_3)$-	V[106]		
$(C_2H_5)_2NCOCH(CH_3)$-	V[106]		
$CNCH_2CH_2$-	I[87]	64	187–189 (0.5)
$C_2H_5OOCCH_2CH_2$-	V[87]		167–169 (0.2)
$C_2H_5OC({=}NH_2Cl)CH_2CH_2$-	V[87]	101	
$CH_3OOCCH(C_6H_{11})$-	I[101]		
$C_6H_5CH_2$-	I[31, 32, 93]	55, 58	
$C_6H_5CH(CH_3)$-	IV[44]		
$C_6H_5CH_2CH(CH_3)$-	I[41, 43]	94	
$C_6H_5CH(NH_2)CH(C_6H_5)$-	I[133]	142–145	
	I[132]	27–28	

TABLE XVIII (*Continued*)

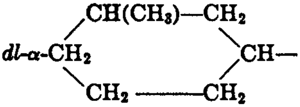
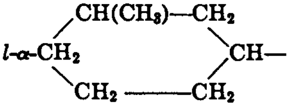
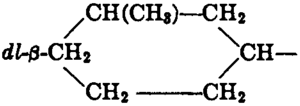
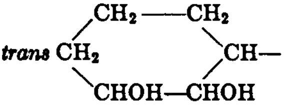
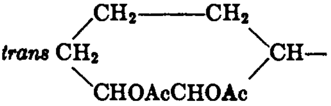
Formula	Method of Preparation	M.P., °C.	B.P., °C. (mm.)
	p-Toluenesulfonates, Alkyl or Alkylene Group (*Continued*)		
	I[133]	46–47	....
	I[133]	36–37	....
	I[133]	71–72	....
	I, V[130]	96–96.4	....
	V[120]	78–79	....
trans-C_6H_{10}(di-)	I[120]	109	....
cis-C_6H_{10}(di-)	I[120]	128.5–129.5	....
l-Menthyl	I[22, 45]	97, 91–92	....
dl-Bornyl	I[131]	80.5	....
d-Bornyl	I[9]	67	Dec. 132
trans *o*-C_6H_{11}-C_6H_{10}	I[110]	122	....
cis α-Decalyl	I[115]	96–98	....
trans α-Decalyl	I[115]	100	....
Cholesteryl	I[111]	....	....
Sitosteryl	I[111]	....	....
Stigmasteryl	I[111]	....	....
α-Ergostenyl	I[111]	162–163	....
Ergostanyl	I[111]	150–151	....
Cholestanyl	I[111]	134–135	....
Sitostanyl	I[111]	154–155	....
α-$C_4H_3O \cdot CH_2$-(furfuryl)	I[40]	Oil	....
α-$C_4H_7O \cdot CH_2$-	I[117, 123]	38.7–39.1	....
$O[CH(CH_3)CH_2]_2CH$-	I[108]	88–89	....
Cinchoninyl	I[114]	173	....
	Cresol Derivatives		
2,3,5-$HO(Br)(CH_3)C_6H_2SO_3CH_3$	I[94]	79–80	....
2,3,5-$HO(Br)(CH_3)C_6H_2SO_3C_2H_5$	I[94]	54–55	....
4,3-$HO(CH_3)C_6H_3SO_3CH_3$	V[118]	93	200 (1)

TABLE XVIII (*Continued*)

Formula	Method of Preparation	M.P., °C.	B.P., °C. (mm.)
Cresol Derivatives (Continued)			
4,3-$CH_3COO(CH_3)C_6H_3SO_3CH_3$	V^{118}	56	....
4,3-$C_6H_5COO(CH_3)C_6H_3SO_3CH_3$	V^{118}	82	....
4,3-$CH_3O(CH_3)C_6H_3SO_3CH_3$	V^{118}	57	....
4,3,5-$HO(CH_3)BrC_6H_2SO_3CH_3$	I,^{93} V^{118}	141–143	....
4,3,5-$HO(CH_3)BrC_6H_2SO_3C_2H_5$	I^{93}	113	....
5,2-$HO(CH_3)C_6H_3SO_3CH_3$	V^{118}	70	....
5,2-$CH_3O(CH_3)C_6H_3SO_3CH_3$	V^{118}	70	....
5,2-$C_6H_5COO(CH_3)C_6H_3SO_3CH_3$	V^{118}	68	....
Benzoic Acid Derivatives			
2-$C_6H_4(COOCH_3)SO_3CH_3$	II^{81}	....	....
2-$C_6H_4(COOCH_3)SO_3C_2H_5$	II^{81}	....	....
2-$C_6H_4(COOC_2H_5)SO_3CH_3$	II^{81}	....	....
2-$C_6H_4(COOC_2H_5)SO_3C_2H_5$	I^{82}	....	212–213 (21)
5,2-$O_2NC_6H_3(COOCH_3)SO_3C_2H_5$	II^{83}	68	....
5,2-$O_2NC_6H_3(COOC_2H_5)SO_3CH_3$	II^{83}	80	....
5,2-$O_2NC_6H_3(COOC_2H_5)SO_3C_2H_5$	II^{83}	65–66	....
5,4,2-$O_2N(CH_3)C_6H_2(COOCH_3)SO_3CH_3$	II^{96}	94.5	....
3-$C_6H_4(COOH)SO_3CH_3$	II^{4}	139–140	....
3-$C_6H_4(COOCH_3)SO_3CH_3$	III^{4}	32–33	....
6,3-$BrC_6H_3(COOH)SO_3C_2H_5$	I^{84}	84	....
6,3-$BrC_6H_3(CONH_2)SO_3C_2H_5$	I^{84}	128	....
6,3-$HOC_6H_3(COOC_2H_5)SO_3C_2H_5$	II^{86}	56	....
4-$C_6H_4(COOH)SO_3CH_3$	II^{4}	195–196	....
4-$C_6H_4(COOCH_3)SO_3CH_3$	II, HI^{4}	88–90	....
3,4-$O_2NC_6H_3(COOH)SO_3CH_3$	II^{4}	140–142	....
3,4-$O_2NC_6H_3(COOCH_3)SO_3CH_3$	III^{4}	86–87	....
2,5,4-$CH_3(O_2N)C_6H_2(COOCH_3)SO_3CH_3$	I^{88}	302–305 (dec.)	....
Di- and Trisulfonates			
1,3,5-$C_6H_3(SO_3C_2H_6)_3$	I,^{75} II^{75}	147	....
Biphenyl and Benzophenone Derivatives			
4-$C_6H_5C_6H_4SO_3C_2H_5$	I, II^{69}	73–74	....
4,4′-$O_2NC_6H_4C_6H_4SO_3C_2H_5$	I, II^{70}	168–169	....
3,3′-$(C_6H_4SO_3CH_3)_2$	III^{74}	132.5	....
2-$C_6H_6COC_6H_4SO_3C_2H_5$	I^{81}	125.5–126.5	....
Naphthalene Derivatives			
1-$C_{10}H_7SO_3CH_3$	I,^{88} III^{20}	72–73	....
1-$C_{10}H_7SO_3C_2H_5$	I^{88}	30	131 (0:)
1-$C_{10}H_7SO_3C_{10}H_{19}$ (*l*-menthyl)	I^{100}	....	....

TABLE XVIII (*Continued*)

Formula	Method of Preparation	M.P., °C.	B.P., °C. (mm.)
Naphthalene Derivatives (Continued)			
2-$C_{10}H_7SO_3CH_3$	I,[33] III[20]	56	....
2-$C_{10}H_7SO_3C_2H_5$	I[33]	11–12	134 (0.–)
2-$C_{10}H_7SO_3C_{10}H_{19}$ (*l*-menthyl)	I[100]	114–115	....
4,1-$FC_{10}H_6SO_3C_2H_5$	II[46]	93	....
5,1-$FC_{10}H_6SO_3CH_3$	II[48]	118	....
5,1-$FC_{10}H_6SO_3C_2H_5$	II[48]	79	....
4,1-$ClC_{10}H_6SO_3CH_3$	II[49]	83	....
4,1-$ClC_{10}H_6SO_3C_2H_5$	II[49]	104	....
5,1-$ClC_{10}H_6SO_3CH_3$	II[50]	89	....
5,1-$ClC_{10}H_6SO_3C_2H_5$	II[50]	46	....
6,1-$ClC_{10}H_6SO_3C_2H_5$	II[51]	114.5	....
7,1-$ClC_{10}H_6SO_3CH_3$	II[49]	115	....
8,1-$ClC_{10}H_6SO_3CH_3$	II[52]	70	....
8,1-$ClC_{10}H_6SO_3C_2H_5$	II[52]	67.5	....
1,2-$ClC_{10}H_6SO_3C_2H_5$	II[53, 58]	104–105	....
4,2-$ClC_{10}H_6SO_3C_2H_5$	II[60]	76	....
5,2-$ClC_{10}H_6SO_3C_2H_5$	II[50]	111	....
6,2-$ClC_{10}H_6SO_3CH_3$	II[49]	89	....
6,2-$ClC_{10}H_6SO_3C_2H_5$	II[49]	....	....
7,2-$ClC_{10}H_6SO_3CH_3$	II[51]	89	....
7,2-$ClC_{10}H_6SO_3C_2H_5$	II[51]	65	....
8,2-$ClC_{10}H_6SO_3C_2H_5$	II[51]	90	....
4,5,1-$Cl_2C_{10}H_5SO_3C_2H_5$	II[58]	106	....
4,7,1-$Cl_2C_{10}H_5SO_3CH_3$	II[53]	78–79	....
4,7,1-$Cl_2C_{10}H_5SO_3C_2H_5$	II[58]	154	....
7,8,1-$Cl_2C_{10}H_5SO_3C_2H_5$	II[56]	132	....
5,6,2-$Cl_2C_{10}H_5SO_3C_2H_5$	II[59]	128	....
7,8,2-$Cl_2C_{10}H_5SO_3C_2H_5$	II[61]	123	....
5,1-$BrC_{10}H_6SO_3CH_3$	II[47]	77	....
5,1-$BrC_{10}H_6SO_3C_2H_5$	II[54, 61]	51	....
5,1-$BrC_{10}H_6SO_3C_3H_7$-*n*	II[47]	57–58	....
5,1-$BrC_{10}H_6SO_3C_3H_7$-*iso*	II[47]	74	....
5,8,2-$Br_2C_{10}H_5SO_3C_2H_5$	I[62, 63]	156–157	....
5,1-$IC_{10}H_6SO_3CH_3$	II[55]	59–60	....
5,1-$IC_{10}H_6SO_3C_2H_5$	II[55]	75	....
5,1-$IC_{10}H_6SO_3C_3H_7$-*n*	II[55]	67	....
5,1-$IC_{10}H_6SO_3CH(CH_3)_2$	II[55]	90	....
4,1-$O_2NC_{10}H_6SO_3CH_3$	II[58]	117	....
4,1-$O_2NC_{10}H_6SO_3C_2H_5$	II[58]	93	....
5,1-$O_2NC_{10}H_6SO_3CH_3$	I[57]	117.5	....
5,1-$O_2NC_{10}H_6SO_3C_2H_5$	II[56, 57]	101–102	....
8,1-$O_2NC_{10}H_6SO_3CH_3$	I[57]	124	....
8,1-$O_2NC_{10}H_6SO_3C_2H_5$	I[57]	118	....
4,2-$O_2NC_{10}H_6SO_3C_2H_5$	II[64]	114.5	....

TABLE XVIII (*Continued*)

Formula	Method of Preparation	M.P., °C.	B.P., °C. (mm.)
	Naphthalene Derivatives (Continued)		
$5,2\text{-}O_2NC_{10}H_6SO_3C_2H_5$	II[65, 66]	114–115	....
$8,2\text{-}O_2NC_{10}H_5SO_3C_2H_5$	II[66, 67]	106	....
$5,6,1\text{-}O_2N(Cl)C_{10}H_5SO_3C_2H_5$	II[58]	110	....
$8,7,1\text{-}O_2N(Cl)C_{10}H_5SO_3C_2H_5$	II[58]	181	....
$1,8,2\text{-}O_2N(Cl)C_{10}H_5SO_3C_2H_5$	II[58]	124	....
$5,1,2\text{-}O_2N(Cl)C_{10}H_5SO_3C_2H_5$	II[58]	116	....
$5,6,2\text{-}O_2N(Cl)C_{10}H_5SO_3C_2H_5$	II[58]	139	....
$5,8,2\text{-}O_2N(Cl)C_{10}H_5SO_3C_2H_5$	II[58]	89	....
$8,5,2\text{-}O_2N(Cl)C_{10}H_5SO_3C_2H_5$	II[58]	123	....
$8,7,2\text{-}O_2N(Cl)C_{10}H_5SO_3C_2H_6$	II[51]	184	....
$4,5,2\text{-}(O_2N)_2C_{10}H_5SO_3C_2H_6$	II[58]	153–154	....
$1,5\text{-}C_{10}H_6(SO_3CH_3)_2$	I[33]	205	....
	Acenaphthene Derivatives		
$3\text{-}C_{12}H_9SO_3CH_3$	III[67]	122–123	....
$3\text{-}C_{12}H_9SO_3C_2H_6$	III[67]	87–88	....
	Anthracene and Phenanthrene Derivatives		
$2\text{-}C_6H_4(CH)_2C_6H_3SO_3CH_3$	I[71]	157	....
$2\text{-}C_6H_4(CH)_2C_6H_3SO_3C_2H_5$	I[71]	160	....
$2\text{-}C_6H_4(\underline{CH\text{-}CH})C_6H_3SO_3CH_3$	I,[88] III[72]	96–98 (101.5)	....
$2\text{-}C_6H_4(\underline{CH\text{-}CH})C_6H_3SO_3C_2H_6$	1[88]	88.5	....
$3\text{-}C_6H_4(\underline{CH\text{-}CH})C_6H_3SO_3CH_3$	I,[73] III[73]	119-120	....
$3\text{-}C_6H_4(\underline{CH\text{-}CH})C_6H_3SO_3C_2H_6$	I[73]	107–108	....
$9\text{-}C_6H_4(\underline{CH\text{-}C\text{-}})C_6H_4SO_3CH_3$	III[91]	106	....
$9\text{-}C_6H_4(\underline{CH\text{-}C\text{-}})C_6H_4SO_3C_2H_6$	III[91]	108	....
$9,3\text{-}C_6H_4(\underline{CCl\text{-}CH})C_6H_3SO_3CH_3$	III[90]	172–172.5	....
$9,3\text{-}C_6H_4(\underline{CCl\text{-}CH})C_6H_3SO_3C_2H_6$	III[90]	182.5–183	....
$9,3\text{-}C_6H_4(\underline{CBr\text{-}CH})C_6H_3SO_3CH_3$	III[90]	172.5–173	....
$9,3\text{-}C_6H_4(\underline{CBr\text{-}CH})C_6H_3SO_3C_2H_6$	III[90]	173–173.3	....
$10,3\text{-}C_6H_4(\underline{CH\text{-}CBr})C_6H_3SO_3CH_3$	III[90]	158	....
$10,3\text{-}C_6H_3(\underline{CH\text{-}CBr})C_6H_3SO_3C_2H_6$	III[90]	143.5 (134)	....
$2\text{-}C_6H_4(CO)_2C_6H_3SO_3CH_3$	I[71]	123	....
$2\text{-}C_6H_4(CO)_2C_6H_3SO_3C_2H_5$	I[71]	125	....
$3\text{-}C_6H_4(\underline{COCO})C_6H_3SO_3CH_3$	Oxid.[71, 90]	235	....
$2\text{-}C_6H_4(\underline{COCO})C_6H_3SO_3CH_3$	Oxid.[90]	196–197	....
$C_{23}H_{17}Br(SO_3CH_3)_2$	III[90]	294–295	....
A-retene-SO_3CH_3	III[90]	164–166	....
B-retene-SO_3CH_3	III[90]	117–119	....

[1] Krafft and Roos, *Ber.*, **25**, 2257 (1892).
[2] Hübner, *Ann.*, **223**, 237 (1884).
[3] Praetorius, *Monatsh.*, **26**, 8 (1905).
[4] Wegscheider and Furcht, *Monatsh.*, **23**, 1095 (1902); see also *Ber.*, **35**, 4830 (1902).
[5] Schiller and Otto, *Ber.*, 9, 1689 (1876).
[6] Praetorius, *Monatsh.*, **28**, 784 (1907).
[7] Vörlander and Nolte, *Ber.*, **46**, 3219 (1913).
[8] Patterson and Frew, *J. Chem. Soc.*, 89, 333 (1906).
[9] Ferns and Lapworth, *ibid.*, **101**, 276 (1912).
[10] Otto and Rössing, *Ber.*, 19, 1225 (1886).
[11] Sekera and Marvel, *J. Am. Chem. Soc.*, **55**, 347 (1933); *Org. Syntheses*, **20**, 50 (1940).
[12] Willgerodt and Klinger, *J. prakt. Chem.*, [2] **85**, 191 (1912).
[13] Carpenter, M. S. thesis, Northwestern University, 1935.
[14] Colgate and Rodd, *J. Chem. Soc.*, **97**, 1600 (1910).
[15] Boyle, *ibid.*, 99, 332 (1911).
[16] Boyle, *ibid.*, **97**, 216 (1910).
[17] Kastle and Murrill, *Am. Chem. J.*, **17**, 292 (1895).
[18] Boyle, *J. Chem. Soc.*, **95**, 1704 (1909).
[19] Flurscheim, *J. prakt. Chem.*, [2] **71**, 525 (1905).
[20] Ullmann and Wenner, *Ann.*, **327**, 121 (1903).
[21] Jaworski, *Z. Chem.*, 221 (1865).
[22] Hilditch, *J. Chem. Soc.*, 99, 238 (1911).
[23] Rodionov, *Bull. soc. chim.*, **39**, 305 (1925).
[24] Finzi, *Ann. chim. applicata*, **15**, 41 (1925).
[25] Izmail' skii and Razorenov, *J. Russ. Phys.-Chem. Soc.*, **52**, 359 (1920); *C.A.*, **18**, 1481 (1924).
[26] Földi, *Ber.*, **53B**, 1836 (1920).
[27] Slotta and Lorenz, *Ber.*, **58B**, 1320 (1925).
[28] Houben and Schreiber, *Ber.*, **53B**, 2346 (1920).
[29] Clemo and Perkin, *J. Chem. Soc.*, **121**, 642 (1922).
[30] Gilman and Beaber, *J. Am. Chem. Soc.*, **45**, 841 (1923).
[31] Gilman and Beaber, *ibid.*, **47**, 522 (1925).
[32] Hahn and Walter, *Ber.*, **64B**, 1531 (1931).
[33] Rodionov, *Bull. soc. chim.*, **45**, 109 (1929).
[34] Slotta and Franke, *Ber.*, **63B**, 678 (1930).
[35] Blanchard, *Bull. soc. chim.*, **41**, 824 (1927).
[36] Kereszty and Wolf, German pat., 353,195, *C.A.*, **17**, 1243 (1923).
[37] Clemo and Walton, *J. Chem. Soc.*, 723 (1928).
[38] Földi, *Ber.*, 60B, 656 (1927).
[39] Demény, *Rec. trav. chim.*, **50**, 60 (1931).
[40] Gilman and Brown, *Iowa State Coll. J. Sci.*, 6, 11 (1931).
[41] Phillips and Pittman, *J. Chem. Soc.*, **123**, 44 (1923).
[42] Hantzsch and Müller, *Ber.*, **62B**, 966 (1929).
[43] Kenyon and co-workers, *J. Chem. Soc.*, 1072 (1935).
[44] Kenyon, Phillips, and Taylor, *ibid.*, 173 (1933).
[45] Rule and Smith, *ibid.*, 1482 (1931).
[46] Mauselius, *Öf. Kongl. (Svenska) v.-Akad. Fordhandlingar*, **443** (1890).
[47] Mauselius, *ibid.*, 563 (1889).
[48] Mauzelius, *Ber.*, **22**, 1845 (1889).
[49] Arnell, dissertation, Upsala, 1889; *Ber.*, **17R**, 48 (1884).
[50] Backstrom, *Z. Kryst. Min.*, **24**, 261 (1895); Cleve, *Ber.*, **20**, 72 (1887).
[51] Cleve, *Ber.*, **25**, 2482 (1892).
[52] Cleve, *Ber.*, **23**, 960 (1890).
[53] Cleve, *Ber.*, **24**, 3478 (1891).
[54] Mauselius, *Ber.*, **20**, 3407 (1887).
[55] Mauselius, *Ber.*, **22**, 2821 (1889).
[56] Cleve, *Bull. soc. chim.*, [2] **24**, 510 (1875).
[57] Erdmann and Süvern, *Ann.*, **275**, 245 (1893).
[58] Cleve, *Chem.-Ztg.*, **17**, 398 (1893).
[59] de Ruijter de Wildt, *Rec. trav. chim.*, **23**, 181 (1904).
[60] Cleve, *Ber.*, **21**, 3274 (1888).
[61] Mauselius, *Ber.*, **20**, 3407 (1887).
[62] Armstrong and Rossiter, *Chem. News*, **65**, 58 (1892).
[63] Krafft and Roos, *Ber.*, **28**, 2823 (1895).

[64] Cleve, *Ber.*, **19**, 2180 (1886).

[65] Cleve, *Bull. soc. chim.*, [2] **26**, 446 (1876).

[66] Palmaer, *Ber.*, **21**, 3263 (1888).

[67] Cleve, *Bull. soc. chim.*, [2] **29**, 415 (1878).

[68] Hellstrom, *Öf. Kongl. (Svenska) v. Akad. Farhandlingar*, 618 (1888).

[69] Gabriel and Deutsch, *Ber.*, **13**, 388 (1880).

[70] Gabriel and Dambergis, *Ber.*, **13**, 1408 (1880).

[71] Heffter, *Ber.*, **28**, 2261 (1895).

[72] Werner, *Ann.*, **321**, 274 (1902).

[73] Sandqvist, *Ann.*, **369**, 115 (1909).

[74] Schultz and Kohlhaus, *Ber.*, **39**, 3345 (1906).

[75] Jackson and Wing, *Am. Chem. J.*, **9**, 337 (1887).

[76] Lagai, *Ber.*, **25**, 1836 (1892).

[77] Peratoner, *Gazz. chim. ital.*, **281**, 234 (1898).

[78] Lassar-Cohn and Löwenstein, *Ber.*, **41**, 3366 (1908).

[79] Zincke and Brune, *Ber.*, **41**, 904 (1908).

[80] Gnehm and Knecht, *J. prakt. Chem.*, [2] **74**, 96 (1906).

[81] (*a*) Remsen and Saunders, *Am. Chem. J.*, **17**, 358 (1895). (*b*) Remsen and Dohme, *ibid.*, **11**, 343 (1889).

[82] Cobb, *ibid.*, **35**, 493 (1906).

[83] Kastle, *ibid.*, **11**, 194 (1889).

[84] Böttinger, *Ann.*, **191**, 19, 28 (1878).

[85] Karslake and Huston, *J. Am. Chem. Soc.*, **31**, 1059 (1909).

[86] Mendius, *Ann.*, **103**, 62 (1857).

[87] Oliveri-Mandalà, *Atti accad. Lincei*, [5] **21**, I, 781 (1912).

[88] Sandqvist, *Ann.*, **379**, 87 (1911).

[89] Sandqvist, *Ann.*, **398**, 132 (1913).

[90] Sandqvist, *Ann.*, **417**, 11, 26 (1916).

[91] Sandqvist, *Ann.*, **392**, 86 (1912).

[92] Sandqvist, *Chem. Zentr.*, II, 1032 (1918).

[93] Zincke and Brune, *Ber.*, **44**, 188 (1911).

[94] Zincke and Kempf, *Ber.*, **44**, 417 (1911).

[95] Karslake and Bond, *J. Am. Chem. Soc.*, **38**, 1347 (1916).

[96] Tabern and Volwiler, *ibid.*, **56**, 1139 (1934).

[97] Nair and Peacock, *J. Indian Chem. Soc.*, **12**, 318 (1935).

[98] Medvedev and Alekseeva, *Ber.*, **65B**, 131 (1932).

[99] Komppa and Wahlforss, *J. Am. Chem. Soc.*, **52**, 5013 (1930).

[100] Patterson and McAlpine, *J. Chem. Soc.*, 353 (1927).

[101] Freudenberg and Markert, *Ber.*, **58B**, 1753 (1925).

[102] Freudenberg and Rhino, *Ber.*, **57B**, 1547 (1924).

[103] Borsche and Frank, *Ber.*, **59B**, 237 (1926).

[104] Bachman, *J. Am. Chem. Soc.*, **57**, 382 (1935).

[105] Roos, Gilman, and Beaber, *Org. Syntheses*, 9, 28 (1929).

[106] Clemo and Tenniswood, *J. Chem. Soc.*, 2549 (1931).

[107] Rossander and Marvel, *J. Am. Chem. Soc.*, **50**, 1491 (1928).

[108] Freudenberg and Markert, *Ber.*, **60B**, 2247 (1927).

[109] Bell, *J. Chem. Soc.*, 2770 (1928).

[110] Hückel, Neunhoeffer, Gercke, and Frank, *Ann.*, **477**, 99 (1929).

[111] Stoll, *Z. physiol. Chem.*, **207**, 147 (1932).

[112] Slotta and Behnisch, *Ber.*, **66B**, 360 (1933).

[113] Butler, Nelson, Renfrew, and Cretcher, *J. Am. Chem. Soc.*, **57**, 575 (1935).

[114] Suszko and Tomanek, *Rec. trav. chim.*, **52**, 18 (1933).

[115] Hückel, Danneel, Gross, and Naab, *Ann.*, **502**, 99 (1933).

[116] McLang, *Chem. Trade J.*, **83**, 143 (1928).

[117] Gilman, Brown, Dickey, Hewlett, and Wright, *Proc. Iowa Acad. Sci.*, **36**, 265 (1929).

[118] Frèrejacque, *Ann. chim.*, **14**, 147 (1930).

[119] Butler, Renfrew, Cretcher, and Souther, *J. Am. Chem. Soc.*, **59**, 227 (1937).

[120] Criegee and Stanger, *Ber.*, **69B**, 2753 (1936).

[121] Gerard, Kenyon, and Phillips, *J. Chem. Soc.*, 153 (1937).

[122] Barger, Robinson, and Smith, *ibid.*, 718 (1937).

[123] Prelog, Cerkovnikov, and Ustricev, *Ann.*, **535**, 37 (1938).

[124] Gurvich and Orlova, *Org. Chem. Ind. (U.S.S.R.)*, **2**, 544 (1937); *C.A.*, **32**, 8381 (1938).

[125] Butler, Renfrew, and Clapp, *J. Am. Chem. Soc.*, **60**, 1472 (1938).

The tribenzenesulfonate and *p*-toluenesulfonate of glycerol have been obtained[5] by action of the sulfonyl chlorides upon the mono or disodium derivatives of glycerol. The preparation of *p*-toluenesulfonates of the carbohydrates has been mentioned under reactions of sulfonyl chlorides.

Reactions of Alkyl Sulfonates. The alkyl sulfonates are easily hydrolyzed and pyrolyzed and show a strong alkylating action toward various types of organic compounds. They resemble the alkyl sulfates except for a greater tendency toward formation of reduction products. Unlike the alkyl halides (except methyl iodide) reaction with a Grignard reagent establishes a new carbon-carbon bond rather than producing disproportionation products. Toward most reagents the sulfonates are more reactive than the alkyl iodides and hence alkylations with them may be performed at lower temperatures, reducing the chance for side reactions. Since only one of the alkyl groups of an alkyl sulfate is reactive, alkyl sulfonates are more economical for alkylations where the alkyl group is expensive. A number of alkyl *p*-toluenesulfonates are now available for laboratory use and several have become comparatively inexpensive reagents.

Pyrolysis Reactions. The thermal decomposition of alkyl sulfonates, except for the methyl esters, gives rise to the sulfonic acid and an olefin or its polymerization product. Methyl benzenesulfonate and *p*-toluenesulfonate distil practically without decomposition at 280° and 290°, while ethyl benzenesulfonate gives benzenesulfonic acid and ethylene almost quantitatively.[6] Olefins are the chief products obtained from *β*-chloroethyl and *β*,*β*′-dichloroisopropyl benzenesulfonates but the yields are lower. Allyl and benzyl esters on the other hand give polymeric products. If the decomposition of the benzyl ester is carried out in an aromatic compound as solvent benzylation may occur. The reaction goes best in the range 110–140° and is exothermic. Refluxing benzyl benzenesulfonate with excess benzene yields diphenylmethane together with a small amount of *o*- and *p*-dibenzylbenzenes. Phenol is converted chiefly into *o*- and *p*-benzylphenol together with a little phenyl benzyl ether. Toluene and anisole yield

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[126] Butler and Cretcher, U. S. pat., 2,172,606, *C.A.*, **34**, 1132 (1940); Butler, Cretcher, and Renfrew, *C.A.*, **34**, 1132 (1940).

[127] Fischer and Baer, *Naturwissenschaften*, **25**, 588 (1937).

[128] Green, Renfrew, and Butler, *J. Am. Chem. Soc.*, **61**, 1783 (1939).

[129] Shuer, *Khim. Mashinostroenie*, **8**, No. 8, 19 (1939); *C.A.*, **34**, 3137 (1940); Shuer and Kulbach, *Org. Chem. Ind.* (*U.S.S.R.*), **6**, 551 (1939); *C.A.*, **34**, 5063 (1940).

[130] Smith and Guss, *J. Am. Chem. Soc.*, **62**, 2631 (1940).

[131] Hückel and Pietrzok, *Ann.*, **543**, 230 (1940).

[132] Gough, Hunter, and Kenyon, *J. Chem. Soc.*, 2052 (1926).

[133] Read, Campbell, and Barker, *ibid.*, 2305 (1929).

85 and 77% respectively of the *p*-benzyl compounds. In nitrobenzene only benzenesulfonic acid and a polymer of the benzylidene group could be identified. Ethylene dibenzenesulfonate is converted into acetylene and acetaldehyde, the latter probably coming from secondary changes. Adding sulfuric acid or benzenesulfonic acid to an ester greatly lowers the temperature at which decomposition occurs. Allyl and particularly benzyl benzenesulfonate decompose upon standing at room temperature, the acid formed accelerating the change.

Menthyl benzenesulfonate decomposes when heated for 6 hours at 85–90° to give a mixture of products [7a] from which were isolated hexahydro-*p*-cymene, a dimenthene, and a higher polymer, besides benzenesulfonic acid. In toluene solution the reaction is simplified, the dimenthene being the chief product. When the decomposition is effected by distillation the menthene escapes the polymerizing action of the sulfonic acid and is obtained as such.[7b] The decomposition of the α- and β-naphthalenesulfonates gives analogous results. Bornyl esters yield, besides camphene, dibornylene and more complex materials.

Hydrolysis. There is considerable contrast in the behavior of alkyl sulfonates and esters of carboxylic acids toward hydrolytic agents. Methyl benzenesulfonate reacts with water at room temperature [8] some fifteen times as rapidly as does methyl benzoate. The rate at which an alkyl sulfonate hydrolyzes is not appreciably affected by an increase in the hydrogen-ion concentration [9] of the solution while for carboxylic esters the rate goes through a minimum in slightly acid solutions. If methyl benzenesulfonate is heated with even dilute hydrochloric acid methyl chloride formation becomes an important feature of the reaction. The rate at which this ester hydrolyzes in solu-

$$C_6H_5SO_3CH_3 + HCl \rightarrow C_6H_5SO_3H + CH_3Cl$$

tions of various acidities has been reported in detail.[10] Ethyl benzenesulfonate and undoubtedly also the higher esters are not as readily hydrolyzed as the first member of the series.[11]

The action of aqueous ammonia on ethyl benzenesulfonate gives chiefly hydrolysis products [12] but a small amount of benzenesulfonamide and of ethylamine were also found. Hydrazine hydrate produces

$$C_6H_5SO_3C_2H_5 + NH_3 \rightarrow C_6H_5SO_2NH_2 + C_2H_5OH$$

$$C_6H_5SO_3C_2H_5 + NH_3 \rightarrow C_6H_5SO_3NH_3C_2H_5$$

complete hydrolysis in cold aqueous solution,[13] the reaction occurring more rapidly than with ammonia.[14]

In an investigation of the hydrolysis of ethyl *p*-bromobenzenesulfonate in acetone solution [15] to which a small amount of water had been added it was noted that the hydrolysis reactions as determined by titration of the solution were much slower in the presence of halogen acids and their salts than when water alone was present. It was found that this apparently slow hydrolysis was accounted for by side reactions which used up the ester in the formation of alkyl halides. With 1 *N* hydrochloric acid the formation of ethyl chloride occurred nearly three times as rapidly as the formation of the ethyl alcohol. When allowance was made for these side reactions the hydrolysis rate appeared to be slightly higher for acid solutions than where water was used alone.

A study [9c] of the effect of a substituent in the aromatic nucleus upon the rate at which an alkyl sulfonate hydrolyzes demonstrated that a nitro group had a powerful accelerating influence while a *para* methyl reduced the reaction rate. The esters were dissolved in 30% alcohol containing a low concentration of alkali and the hydrolysis rates determined for 25°. The results are summarized in Table XIX. These

TABLE XIX

Alkyl Sulfonate	*K* Calc. for Monomol. Reaction	*K* Calc. for Bimol. Reaction	Alkalinity of Solution
$C_6H_5SO_3C_2H_5$	0.00036	0.46	0.005 *N*
o-$O_2NC_6H_4SO_3C_2H_5$	0.0073 0.0077	1.23	neutral 0.0017 *N*
m-$O_2NC_6H_4SO_3C_2H_5$	0.0022 0.0023 0.0026	11.4	0.0017 *N* 0.0035 *N* 0.006 *N*
p-$O_2NC_6H_4SO_3C_2H_5$	0.0026	19	0.0012 *N*
p-$CH_3C_6H_4SO_3C_2H_6$	0.00019	.....	0.0017 *N*

data and those of a similar nature obtained for the reaction of ethyl *p*-bromobenzenesulfonate with alcohol (see next section) indicate that the commonly employed *p*-toluenesulfonates react much more slowly in alkylations than would various other sulfonates and that a comparison of the usefulness of different esters would be worth while.

Heating ethyl α-naphthalenesulfonate with water to 150° results in complete hydrolysis [16a] to naphthalene, sulfuric acid, and alcohol. Treating β-chloroethyl benzenesulfonate with 0.1 *N* potassium hydroxide [16b] showed that the sulfonate group hydrolyzes three times as rapidly as the chlorine while for β,β′-dichloroisopropyl benzenesulfonate the chlorines are removed at the greater rate. This last ester is, however, very resistant to hydrolysis and is only slowly attacked by boiling 30% sodium hydroxide.

Undoubtedly the most readily hydrolyzed ester so far investigated is allyl benzenesulfonate.[17] One would expect the benzyl ester to show a similar behavior. Since it spontaneously decomposes in a few hours its properties have not been fully investigated.

Reaction with Alcohols. Alkyl sulfonates react with alcohols to give ethers or olefins depending upon the alkyl group and the alcohol.

$$C_6H_5SO_3C_2H_5 + n\text{-}C_3H_7OH \rightarrow n\text{-}C_3H_7OC_2H_5 + C_6H_5SO_3H$$

The ether reaction requires twenty to thirty days to become appreciable at room temperature[18] but goes to completion rapidly[18, 19] at 100°. In Table XX is shown the variation in relative reaction rate with change of the ester and alcohol for a temperature of 100° with a molar ratio of alcohol to ester of 15.[19b]

TABLE XX

SULFONATES AND ALCOHOLS

ALKYL BENZENESULFONATE	Methyl	Ethyl	n-Propyl	Isobutyl	Isoamyl
Methyl	3019	1562	1137	772	827
Ethyl	2311	1130	816	498	546
Isobutyl	584	228	171	96	115
Isoamyl	608	268	195	123	137

On the same basis, K for allyl alcohol with ethyl benzenesulfonate is 649 and for benzyl alcohol 346. With trimethylcarbinol and dimethylethylcarbinol olefins are formed. A study of the reaction of ethyl benzenesulfonate with various alcohols at room temperature[18] gave results similar to those above, ether formation occurring most rapidly with methanol; ethyl, *n*-propyl, and isopropyl alcohols react at about the same rate. The reaction is 15–25% complete at the end of thirty days. A comparison of the rates at which the ethyl esters of benzenesulfonic acid and the *p*-chloro-, *p*-bromo-, and *p*-iodo-compounds react with ethyl alcohol showed that the halogenated esters all react more than twice as rapidly as does ethyl benzenesulfonate. As already mentioned, this observation is important if the relationship holds for other alkylations.

The conversion of alcohols into ethers by boiling with a sulfonic acid[20a] undoubtedly occurs through primary formation of alkyl sulfonates.

Alkyl benzenesulfonates react with sodium ethoxide to give ethers in yields that are at least as great as obtained with iodides.[20b] Ethyl *p*-toluenesulfonate reacts with sodium ethoxide,[20c] potassium benzyloxide,[20c] sodium methylbenzylcarbinoxide,[21a] and the sodium derivative of ethyl lactate[21b] to yield the corresponding ethyl ethers. Other ethers have been prepared in liquid ammonia by a similar reaction.[20d]

The action of *d*-benzylmethylcarbinyl *p*-toluenesulfonate[21a] with either sodium ethoxide or potassium carbonate in alcohol gives a *levo* rotatory ether. On the other hand *l*-menthyl, *d*-bornyl, and decalyl *p*-toluenesulfonates[21c] are converted by sodium ethoxide or ethyl alcohol chiefly into menthene, camphene, and octalin respectively. An investigation of the reactions that occur when *l*-menthyl *p*-toluenesulfonate is heated with potassium acetate in alcohol[21d] showed that in addition to the menthyl acetate (which was formed by Walden inversion) ethyl menthyl ether and menthene were produced. The formation of the menthene was catalyzed by the sulfonic acid produced in the ether formation and was greatly reduced or eliminated in the presence of calcium carbonate. Heating β-decalyl *p*-toluenesulfonate (from the 75° β-decalol) with alcohol and calcium carbonate gave 40% octalin and 60% ether while the ester of the 53° decalol gave 75% octalin and 25% ether. For a discussion of these and other results from a stereochemical standpoint the original papers[20c,d,e] should be consulted. The effect of the configuration of the ester group has also been demonstrated in the sterols.[22a] The *p*-toluenesulfonates of cholesterol and ergosterol with methanol give the methyl ethers while the *epi* compounds are converted into unsaturated hydrocarbons. The relative rates of formation of various ethers were reported in connection with this investigation.

In the reaction between alkyl *p*-toluenesulfonates and alkoxymagnesium halides[20c,22b] alkyl halides are formed at first instead of ethers.

$$2C_7H_7SO_3C_2H_5 + 2C_2H_5OMgBr \rightarrow (C_7H_7SO_3)_2Mg + 2C_2H_5Br + 2(C_2H_5O)_2Mg$$

The use of two moles of ester for one of the magnesium compound results in a further reaction and ether formation.

The methyl ethers of glycerol α,γ-dichlorohydrin, chlorobromohydrin, and chloromethylin ($CH_3OCH_2CHOHCH_2Cl$) have been prepared by the action of methyl *p*-toluenesulfonate upon the alcohols.[23]

Reaction with Phenols. The alkylation of phenolic compounds is readily effected by dissolving them in an excess of 10% sodium hydroxide and heating the solution to boiling with slightly more than the equivalent amount of an alkyl *p*-toluenesulfonate.[24] By this procedure the ethyl ester gives 80–85% yields of the ethers of phenol, the cresols, resorcinol, hydroquinone, guaiacol, the naphthols, and brilliant yellow (74% of chrysophenin). The yield with phenol is somewhat less in liquid ammonia.[20d] Phenol in 25% alkali reacts with the propyl ester[25] to give only a 30% yield of the *n*-propyl ether, but since a 73% yield of the *n*-butyl ether[24b] is obtainable in 10% alkali it seems likely that a lower concentration of alkali would give better results. Propylation of phenol and β-naphthol in acetone gives approximately 70% yields of the ethers.[25]

Phenols containing one nitro group may be converted into the ethyl ethers in 90% yields[26] but di- and trinitrophenols and trinitroresorcinol give no evidence of reacting even when a large excess of the alkyl sulfonate is used. In general other substituents which increase the acidity of the phenol reduce the ease of alkylation.[16]

Although Finzi[24a] claimed that phenols were not alkylated satisfactorily in alcohol solution others[16,25] have found the reaction to go very readily in ethyl or isoamyl alcohol when the phenol is present as the sodium or potassium salt. By this procedure Földi[16] prepared the allyl, β-chloroethyl, and β-bromoethyl ethers of a number of phenolic compounds, including morphine. The β-chloroethyl *p*-toluenesulfonate gives up to 80% yields of β-chloroethyl aryl ethers[27a] but β-bromoethyl benzenesulfonate is an unsatisfactory reagent for preparing the β-bromoethyl ethers[16] because at least one-third of the bromine reacts producing glycol derivatives as by-products.

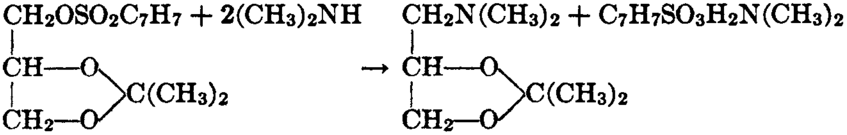
Various ethers of apocupreine have been prepared by the action of the potassium salt in alcohol with esters of *p*-toluenesulfonic acid.[27b]

Monoalkyl ethers of catechol have been prepared in 50% yields by adding 0.95 mole of potassium hydroxide to an alcohol solution containing one mole each of the phenol and ester.[25] Condensation of β-cyanoethyl *p*-toluenesulfonate with resorcinol in the presence of zinc chloride[28a] results in alkylation, ring closure, and loss of ammonia, the product being 7-hydroxy-3,4-dihydrocoumarin.

Thiophenol and *p*-thiocresol have been converted into the ethyl, *n*-propyl, and *n*-butyl aryl sulfides by reaction with the proper *p*-toluenesulfonates.[25,28b]

Reaction with Ammonia and Amines. A 30% yield of methylamine[14] has been obtained by warming methyl *p*-toluenesulfonate with 5% alcoholic ammonia while the ethyl ester under the same conditions gives no more than a trace of ethylamine. Although the experimental conditions are not exactly comparable the alkyl benzenesulfonates give somewhat better results.[12] *l*-Menthyl benzenesulfonate is not changed by warming with alcoholic ammonia, however.[20c]

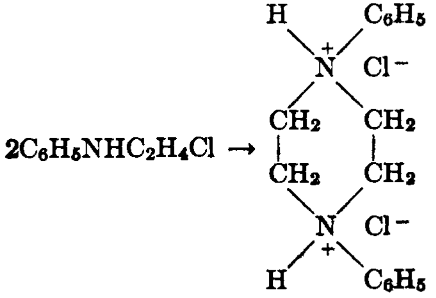
Ethylamine reacts with ethyl benzenesulfonate[12] to give diethylammonium benzenesulfonate but it has also been reported[14] that alcoholic methylamine has little effect upon ethyl *p*-toluenesulfonate. Refluxing equimolecular amounts of *n*-butylamine and lauryl *p*-toluenesulfonate in toluene solution for 6 hours produces a 49% yield of the secondary and 44% of the tertiary amine.[24b] The cetyl ester gives analogous results. A substituted glyceryl *p*-toluenesulfonate yields the tertiary amine when treated with dimethylamine.[29a]



The *p*-toluenesulfonate of ethyl lactate reacts with alcoholic ammonia at 20° with formation of the amide of alanine.[29b] The reaction occurs with Walden inversion.

Aromatic amines also are readily alkylated.[29c] The reaction is strongly exothermic and gives a mixture of products. So far no relationship has been found between the basic properties of an amine and the ease with which it is alkylated. As in other reactions allyl benzenesulfonate reacts with amines much more rapidly than do the alkyl sulfonates. Aniline has been converted into a mixture of mono- and dialkylanilines by treatment with ethyl [20c] or *n*-butyl [24b] *p*-toluene sulfonate; after heating the ethyl ester with a slight excess of aniline to 175–185° for 1 hour [24a] the yield of ethylaniline is 83%. Similar results are obtainable for toluidines [28] and α-naphthylamine [30] with methyl *p*-toluenesulfonate. An 80% yield of the dialkylaniline is produced by heating one mole of aniline with two moles of *n*-propyl *p*-toluenesulfonate and potassium hydroxide.[25] α-Aminopyridine may be propylated or butylated in ether solution in the presence of sodamide. Refluxing an acetone solution of anthranilic acid with methyl *p*-toluenesulfonate [28] gives a 50% yield of the N-methyl compound besides unchanged anthranilic acid and higher methylation products. β-Chloroethyl *p*-toluenesulfonate reacts readily with aniline [27] but the initial product has not been isolated, condensation to a piperazine taking place immediately. From the reaction with methylaniline, however, a small amount of methyl-β-chloroethylaniline was isolated.

$$p\text{-}C_7H_7SO_3C_2H_4Cl + C_6H_5NH_2 \rightarrow C_6H_5NH_2(C_2H_4Cl)O_3SC_7H_7$$



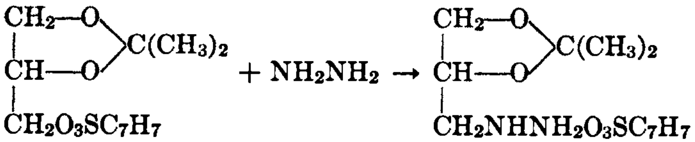
l-Menthyl *p*-toluenesulfonate does not act as an alkylating agent toward aniline or *p*-toluidine, menthene being formed when a mixture of the amine and ester is heated.[20c]

$$p\text{-}CH_3C_6H_4SO_3C_{10}H_{19} + C_6H_5NH_2 \rightarrow C_{10}H_{18} + C_6H_5NH_3O_3SC_7H_7$$

When warmed with tertiary amines alkyl benzene- and *p*-toluenesulfonates readily yield quaternary ammonium salts. Thus methyl,[29] ethyl,[20c] *n*-butyl,[24b] or lauryl *p*-toluenesulfonate reacts with pyridine to give the alkylpyridinium sulfonate, and various alkaloids add the methyl sulfonates.[14, 29, 31a] Methyl *p*-anisolesulfonate has been observed [2] to yield quaternary compounds with hexamethylene tetramine and with alkaloids. The addition products of alkyl *p*-toluene- and the naphthalenesulfonates with dimethylaniline [14, 31a] are obtained nearly quantitatively by heating the reactants to 100°. These addition compounds are excellent alkylating agents for phenolic compounds but do not react with alcohols. Diethylaniline decomposes *d*-bornyl *p*-toluenesulfonate at 145–155° to yield camphene.[20c] The reaction of *d*- or *l*-2-octyl *p*-bromobenzenesulfonate with pyridine or trimethylamine yields an optically active quaternary ammonium salt.[31b]

Methyl benzenesulfonate [32] and *p*-toluenesulfonate have been employed to convert phenylmethylpyrazolone to antipyrene and theobromine to caffeine.[14, 31a]

Reaction with Hydrazine. As noted earlier, hydrazine in aqueous solution yields chiefly hydrolysis products when allowed to react with an alkyl *p*-toluenesulfonate. In the absence of a solvent the ester of a primary alcohol group yields a substituted hydrazine while a secondary alkyl ester gives this and unsaturated compounds.[33]



Inasmuch as aryl esters yield phenols and sulfinates when treated with hydrazine, conversion of lignin into a *p*-toluenesulfonate ($C_{83}H_{83}O_{26}NS_5$) in pyridine followed by a hydrazine decomposition should give an indication of the kind of hydroxyl groups present in the lignin molecule. The results suggest that there are four methoxyl, one phenolic, and four secondary aliphatic (or hydroaromatic) groups. Investigation of the nature of the hydroxyl groups in other products has been carried out similarly.[34]

Reaction with Metallic Salts. Alkyl sulfonates react readily with salts of both inorganic and organic acids and some of these reactions serve as satisfactory preparative methods for the esters.

Methyl and ethyl *p*-toluenesulfonates with aqueous potassium iodide give 85 and 67% respectively of the alkyl iodides under the same conditions.[31,35] The yield of ethyl bromide is about the same as that of the iodide. In the preparation of methyl and ethyl cyanides and of nitromethane and ethane the methyl compounds were also always obtained in higher yields. In a comparison[24b] of *n*-butyl and cetyl *p*-toluenesulfonates in their reaction with an aqueous solution of potassium cyanide it was found that under identical conditions the yields of cyanides were 46 and 86% respectively, indicating the higher alkyl sulfonates to be more reactive or less subject to side reactions than those immediately above methyl. Further evidence on this point will be welcome.

Heating methyl or ethyl *p*-toluenesulfonate with potassium cyanate to 125° gives about a 30% yield of the pure alkyl isocyanate.[36a] Potassium thiocyanate reacts with allyl *p*-toluenesulfonate in aqueous solution[14] to give a 40% yield of allyl isothiocyanate. Cholesteryl *p*-toluenesulfonate[36b] undergoes a similar reaction.

When β-cyanoethyl *p*-toluenesulfonate is heated (80–120°) with potassium carbonate, decomposition[28a] ensues with formation of a 75% yield of vinyl cyanide (acrylonitrile). An even higher yield of ethyl acrylate is produced by a similar decomposition.

$$2p\text{-}C_7H_7SO_3CH_2CH_2COOC_2H_5 + K_2CO_3 \rightarrow$$
$$2C_7H_7SO_3K + 2CH_2{=}CHCOOC_2H_5 + CO_2 + H_2O$$

Several salts have been heated with alkyl *p*-toluenesulfonates in ether solution.[22b] Reaction occurs readily with soluble salts and slowly with others. Magnesium bromide reacts with the butyl ester with precipitation of an 85% yield of magnesium *p*-toluenesulfonate. Ethoxy and phenoxymagnesium iodides give appreciable amounts of *n*-butyl iodide but the ethers were not isolated. The mixed salts, magnesium bromide *p*-toluenesulfinate and magnesium iodide β-naphthalenesulfonate likewise give some alkyl halide while thiophenoxy magnesium iodide and N-methylanilinomagnesium bromide give both the alkyl halide and the alkyl aryl sulfide or amine.

$$C_6H_5SMgI + 2C_7H_7SO_3C_4H_9 \rightarrow C_6H_5SC_4H_9 + C_4H_9I + (C_7H_7SO_3)_2Mg$$

Esterification of an organic acid may be brought about by heating a salt of the acid, either alone or in solution, with an alkyl sulfonate.

After heating a mixture of sodium acetate dihydrate with *n*-butyl *p*-toluenesulfonate at 130–140° for 5 hours the yield of *n*-butyl acetate is 60%. When *d*-benzylmethylcarbinyl *p*-toluenesulfonate is warmed with alcoholic potassium acetate [21a] a mixture of the acetate and ethyl ether results. An 80% yield of ethyl lactate has been obtained from the action of ethyl *p*-toluenesulfonate upon sodium lactate.[21b]

Benzoic acid is readily esterified by dissolving in 10% sodium carbonate and boiling the solution with methyl or ethyl *p*-toluenesulfonate.[24a] It is of interest to note that salicylic acid is readily converted into the ester in similar fashion without affecting the phenolic group while aminobenzoic acids are alkylated on the nitrogen. It seems probable that if a hydroxybenzoic acid were dissolved in two molecular equivalents of alkali, alkylation would occur to the greater extent at the phenolic group.

By heating potassium phthalimide with β-chloroethyl *p*-toluenesulfonate for 3 hours at 200° an 86% yield of the β-chloroethylphthalimide is obtained.[28]

Reaction with Grignard Reagents. It was reported by Moreu [37] that the only products obtained when methyl benzenesulfonate reacts with a Grignard reagent are volatile sulfur compounds having a disagreeable odor and it was not until somewhat later [20c] that the possibility of preparing hydrocarbons by this reaction was recognized. Ethyl *p*-toluenesulfonate was found to react with phenylmagnesium bromide to give a mixture which upon hydrolysis yielded ethylbenzene and benzene. However, from the reaction of ethylmagnesium bromide [38] with the same ester magnesium *p*-toluenesulfonate was the only product isolated and the *l*-menthyl and *d*-bornyl sulfonates are converted into menthene and camphene when treated with a Grignard reagent. These observations demonstrated the dependence of the reaction products upon both the nature of the Grignard reagent and of the ester and led to a more detailed investigation of the reaction. The further observation that phenylmagnesium bromide reacts with the *p*-toluenesulfonate of ethyl lactate [21b,39] to yield ethyl α-bromopropionate as one product was of value later in elucidating the mechanism of the reaction. Undoubtedly ethyl bromide was present in the mixture obtained from phenylmagnesium bromide and ethyl *p*-toluenesulfonate, but it was not detected because its boiling point is practically the same as that of ethyl ether. It was not until the investigation of Rossander and Marvel [40] on the action of γ-chloropropyl *p*-toluenesulfonate with various Grignard reagents that it was discovered that an alkyl halide is always one of the products obtained and that two moles of the alkyl sulfonate are necessary to react with one mole of a

Grignard reagent. The first formulation of the reaction[40] advanced to explain the various products is given below.

(1) $CH_3C_6H_4SO_3R + R'MgBr \rightarrow CH_3C_6H_4SO_3MgBr + RR'$

(2) $CH_3C_6H_4SO_3R + R'MgBr \rightarrow RBr + CH_3C_6H_4SO_3MgR'$

(3) $CH_3C_6H_4SO_3R + CH_3C_6H_4SO_3MgR' \rightarrow (CH_3C_6H_4SO_3)_2Mg + RR'$

If only one mole of ester is added per mole of Grignard reagent the amount of the hydrocarbon, RR′, produced will obviously depend upon the relative rates of reactions (1) and (3) as compared with (2). An alternative way of explaining the formation of the alkyl halide[22b] is indicated by the following equation. If all the alkyl halide is produced according to equation (4) it presupposes that there must be at least as much hydrocarbon formed as there is halide. This is not in accord with the results obtained in many reactions where only one mole of ester is used per mole of Grignard reagent. Thus ethyl lactyl *p*-toluenesulfonate with phenylmagnesium bromide gives no ethyl α-phenylpropionate to correspond to the ethyl α-bromopropionate produced, and in general alkylmagnesium halides[40,41] yield no isolable amount of hydrocarbon under these conditions. The presence of the hydrocarbon derived from the original Grignard in the hydrolysis products may be accounted for by part of the reagent being unused or by the hydrolysis of the product obtained in equation (2).

(4) $CH_3C_6H_4SO_3MgBr + CH_3C_6H_4SO_3R \rightarrow (CH_3C_6H_4SO_3)_2Mg + RBr$

(5) $CH_3C_6H_4SO_3MgR' + H_2O \rightarrow CH_3C_6H_4SO_3MgOH + R'H$

In view of the results obtained by a study of the reaction between alkyl sulfates and Grignard reagents (see Chapter I on alkyl sulfates, p. 59), it seems probable that none of the above formulations is strictly accurate and the formation of hydrocarbons and halides is best accounted for by writing the Grignard reagent in the bimolecular form.[42] Obviously the reactions of equations (6), (7), and (8) may

(6) $2CH_3C_6H_4SO_3R + R'_2Mg \cdot MgBr_2 \rightarrow (CH_3C_6H_4SO_3)_2Mg + 2RBr + R'_2Mg$

(7) $R'_2Mg + 2CH_3C_6H_4SO_3R \rightarrow 2RR' + (CH_3C_6H_4SO_3)_2Mg$

(8) $2CH_3C_6H_4SO_3R + R'_2Mg \cdot MgBr_2 \rightarrow (CH_3C_6H_4SO_3)_2Mg + MgBr_2 + 2RR'$

occur stepwise giving products the same as those of equations (1) and (2). The only important difference is that according to the last formulation the unreacted Grignard reagent is present in the solution as R'_2Mg rather than as the insoluble $CH_3C_6H_4SO_3MgR'$. By analogy with the behavior of the alkyl sulfates it is likely that this latter is present in only minor amount.

The formation of an alkyl halide and a hydrocarbon rarely accounts for more than two-thirds of the Grignard reagent or alkyl sulfonate. One side reaction which occurs to a variable degree results in sulfone formation.[22b,43] The extent of this depends upon the reactivity of the

$$p\text{-}CH_3C_6H_4SO_3C_4H_9\text{-}n + C_6H_5MgBr \rightarrow p\text{-}CH_3C_6H_4SO_2C_6H_5 + C_4H_9OMgBr$$

alkyl group, a highly reactive ester such as allyl giving no sulfone. Esters of aliphatic sulfonic acids give larger yields of sulfones than do alkyl *p*-toluenesulfonates.

Aside from any interest in the mechanism involved, the reaction of alkyl *p*-toluenesulfonates with Grignard reagents is of considerable value in synthesis. Aryl and benzylmagnesium halides[22b,44] may be expected[45] to give 40% or higher of the hydrocarbon when treated with an alkyl *p*-toluenesulfonate. Alkylmagnesium halides containing six or more carbons also give satisfactory results. A useful method for preparing alkyl halides otherwise difficult to obtain is to treat a Grignard reagent with γ-chloropropyl *p*-toluenesulfonate.[40,46a] The yields of chlorides obtained from aryl, benzyl, cyclohexyl, and the

$$C_6H_{13}MgBr + 2p\text{-}CH_3C_6H_4SO_3CH_2CH_2CH_2Cl \rightarrow C_6H_{13}CH_2CH_2CH_2Cl + BrCH_2CH_2CH_2Cl + (CH_3C_6H_4SO_3)_2Mg$$

higher alkyl Grignard reagents range from 40 to 60%. β-Chloroethyl *p*-toluenesulfonate also may be used in this reaction but since most of the even-carbon alkyl halides are otherwise obtainable this is of less interest. It has been reported[46b] that heptynylmagnesium bromide does not react normally with β-bromoethyl *p*-toluenesulfonate.

Alkylation of Ethyl Malonate and Acetoacetate. It was reported by Peacock and Tha[47] that alkylation of ethyl sodiomalonate with ethyl or β-phenoxyethyl *p*-toluenesulfonate gives a satisfactory yield of substituted malonic ester but that the reaction proceeds more slowly than with alkyl halides. This seems remarkable in view of the rapid alkylations in other reactions when the sulfonates are employed, and indeed it was noticed later by Tabern and Volwiler[48] that ethyl sodioethylmalonate reacts vigorously with diethylcarbinyl or methylpropylcarbinyl *p*-toluenesulfonate at room temperature. The yields of dialkylmalonic ester were low, however, possibly due to pentene formation since sodium *p*-toluenesulfonate was formed in large amount. On the other hand ethyl, *n*-propyl, *n*-amyl, and even isopropyl *p*-toluenesulfonates give excellent yields of alkylation product.

$$NaC(C_2H_5)(COOC_2H_5)_2 + C_7H_7SO_3CH(C_2H_5)_2 \rightarrow CH_3CH{=}CHC_2H_5 + CH_2(COOC_2H_5)_2 + C_7H_7SO_3Na$$

Alkylation of ethyl malonate with β-cyanoethyl *p*-toluenesulfonate gives a mixture of mono- and di- derivatives.[49a] In contrast to this β-chloroethyl *p*-toluenesulfonate does not react appreciably. Ethoxyethyl benzenesulfonate gives a 65% yield of alkylation product.[49b]

Ethyl sodioacetoacetate has been alkylated by reaction with β-phenoxyethyl *p*-toluenesulfonate[50] in alcohol solution. The *m*- and *p*-chlorophenoxy and β-naphthoxyethyl esters have been utilized in similar reactions. β-Chloroethyl *p*-toluenesulfonate reacts but the products could not be purified.[49a]

Alkylation of Acetylides. Sodium salts of acetylene[24c] and aryl and alkylacetylenes are readily alkylated by the lower alkyl *p*-toluenesulfonates. The yields are 70% with sodium phenylacetylide but drop to 50% for the alkylacetylenes,[51a] and to 20–25% where allyl *p*-toluenesulfonate is the alkylating agent.

$$C_6H_5C{\equiv}CNa + C_7H_7SO_3C_2H_5 \rightarrow C_6H_5C{\equiv}CC_2H_5 + C_7H_7SO_3Na$$

Alkyl *p*-Toluenesulfonates in the Friedel-Crafts and Related Reactions. Ethyl p-toluenesulfonate gives a 64% yield of ethylbenzene when warmed with benzene and aluminum chloride.[28] The β-cyanoethyl and β-ethylcarboxyethyl esters behave similarly giving over 70% yields of products. β-Chloroethyl *p*-toluenesulfonate reacts with two molecules of benzene to give dibenzyl. It has been reported in the patent literature[51b] that a variety of aromatic compounds undergo nuclear alkylation by simply heating with an alkyl or aralkyl sulfonate to a high temperature. Benzyl sulfonates[5] are apparently more reactive than ordinary alkyl esters.

$$C_6H_6 + C_7H_7SO_3CH_2CH_2COOC_2H_5 \xrightarrow{AlCl_3} C_6H_5CH_2CH_2COOC_2H_5 + C_7H_7SO_3H$$

Reactions of Optically Active Sulfonates. In 1923 the discovery was made[21a] that a Walden inversion occurs in most alkylations where the reagent is an optically active ester of *p*-toluenesulfonic acid. Reactions of this type have been subsequently studied in detail because the problem of determining in which of two reactions inversion occurs is here readily solved, which is not true for the classic examples of this phenomenon. For example *d*-benzylmethylcarbinyl *p*-toluenesulfonate reacts with potassium acetate in alcohol to give *l*-benzylmethylcarbinyl acetate and with sodium ethoxide to form the *l*-ether. The

$$d\text{-}C_7H_7SO_3CH(CH_3)CH_2C_6H_4 + C_2H_5ONa \rightarrow l\text{-}C_6H_5CH_2CH(CH_3)OC_2H_5 + C_7H_7SO_3Na$$

configurations of the acetate and ether are certain as they can be synthesized by reactions in which the carbon-oxygen valence bond is undisturbed. Inversion in the sulfonate alkylations is nearly complete; the alcohol obtained by hydrolysis of the acetate had the value for

$$d\text{-}C_6H_5CH_2CH(CH_3)OK + C_2H_5Br \rightarrow d\text{-}C_6H_5CH_2CH(CH_3)OC_2H_5$$

$\alpha^{23°}_{5461}$ of -32.18 while the original *d*-alcohol from which the *p*-toluenesulfonate was made had $\alpha^{23°}_{5461}$ $+33.02$.

Comprehensive investigations of the reactions undergone by optically active *p*-toluenesulfonates of *sec*-butyl[52] and *β*-octyl alcohols, benzylmethylcarbinol, phenylmethylcarbinol, menthol,[21d,e,f,53] lactic acid,[54a] and *β*-hydroxy-*β*-phenylpropionic acid[54b] indicate that inversions occur in alkylation of a salt, a Grignard reagent, pyridine, and phenol, but not *p*-toluidine. In the reactions of ammonia and piperidine with the *sec*-butyl and *β*-octyl esters there was no proof of inversion. Alkylations involving the menthyl ester as mentioned earlier yield a menthene as the chief product. The phenylmethylcarbinyl sulfonate is so unstable that its behavior was investigated by synthesizing it from the sulfinate by oxidation with hydrogen peroxide in the mixture where the alkylation was to take place.

The inversion of the carbon bearing the hydroxyl group in cinchonine[55] has been accomplished by action of potassium benzoate on the *p*-toluenesulfonate in alcohol.

Substitution Reactions. When bromine is added to methyl 4-hydroxy-3-methylbenzenesulfonate in the cold two reactions occur.[56] The hydrogen bromide liberated in a substitution reaction attacks a second molecule of ester with formation of methyl bromide.

$$4,3\text{-}HO(CH_3)C_6H_3SO_3CH_3 + Br_2 \rightarrow HO(CH_3)(Br)C_6H_2SO_3CH_3 + HBr$$

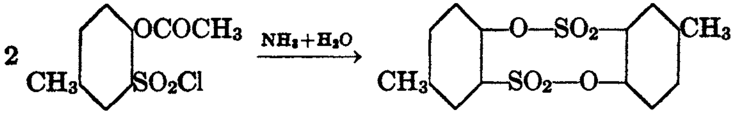
$$4,3\text{-}HO(CH_3)C_6H_3SO_3CH_3 + HBr \rightarrow 4,3\text{-}HO(CH_3)C_6H_3SO_3H + CH_3Br$$

At 100° a second bromine enters the molecule with elimination of the sulfo group in the usual manner. It is possible to analyze phenolsulfonates by liberation of sulfuric acid through excess bromine followed by precipitation of the sulfur as barium sulfate. The quaternary salts obtained from alkyl phenolsulfonates and a tertiary base may also be analyzed by this method.

ARYL SULFONATES

Preparation and Physical Properties. The reaction of an aromatic sulfonyl chloride with a phenol usually yields the aryl sulfonate. The normal and also the abnormal reaction whereby the hydroxyl group is replaced by halogen have been described in detail under reactions of sulfonyl chlorides (see p. 508). Since aryl sulfonates are exceptionally stable to hydrolysis compared with other esters many of the known compounds of this group have been prepared by nitration, bromination, and oxidation reactions of simpler esters. In Table XXI are listed the aryl sulfonates. In the last column I refers to preparation by the sulfonyl chloride-phenol reaction while II refers to any one of several miscellaneous procedures, usually a substitution or oxidation reaction of some compound prepared by method I. The aryl sulfonates are nearly all crystalline solids which are suitable for the identification of phenols or sulfonic acids. The esters of benzene- and *p*-toluenesulfonic acid are by far the most numerous.

Not included in Table XXI are several cyclic disulfonates. The action of ammonia or diethylamine upon a sulfonyl chloride bearing an ortho acetoxy group [57] yields one of these.



Others result from the action of phosphorus oxychloride upon 2,4,6-trihydroxybenzenesulfonic acid,[58a] and the 2,3,4-isomer.[57] One other unusual preparation of a sulfonate should be mentioned. 1-Nitroso-2-naphthol condenses with *p*-toluenesulfinic acid to give a sulfone-sulfonate.

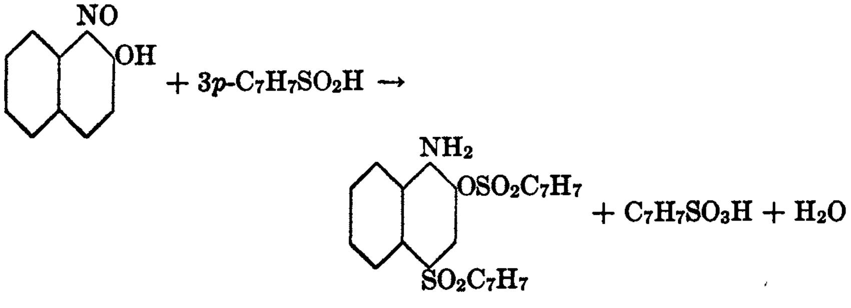


TABLE XXI

Aromatic Esters of Sulfonic Acids

Aryl Group	M.P. (B.p. [mm.]), °C.	Prep. Method and Reference
A. Aryl Benzenesulfonates		
C_6H_5-	34–35	I[57, 58, 59]
2,4,6-$Cl_3C_6H_2$-	66	I[60]
2-BrC_6H_4-	54–56	I[1]
3-BrC_6H_4-	(217–218[10.5])	I[1]
4-BrC_6H_4-	50–55	I[1]
2,4,6-$Br_3C_6H_2$-	85, 99	I[60, 61]
4-IC_6H_4-	52–53	I[62]
2,4,6-$I_3C_6H_2$-	155	I[60]
2-$O_2NC_6H_4$-	75	I[63]
3-$O_2NC_6H_4$-	72–73	I[63]
4-$O_2NC_6H_4$-	82	I,[63] II[58]
2,4-$(O_2N)_2C_6H_3$-	118	I[63]
2-$H_2NC_6H_4$-	87–87.3	I[3]
2-$CH_3CONHC_6H_4$-	95–96	I[9]
2-$C_6H_5CONHC_6H_4$-	90.5–91	II[3]
2-$C_6H_5SO_2NHC_6H_4$-	134	I[3]
2-$(C_6H_5SO_2)_2NC_6H_4$-	164–165	II[3]
2-$[CH_3CO(C_6H_5SO_2)N]C_6H_4$-	115–116	II[3]
2-$[C_6H_5CO(C_6H_5SO_2)N]C_6H_4$-	125.5–126	II[3]
2-$[C_6H_5CH_2(C_6H_5SO_2)N]C_6H_4$-	144.5–145.5	II[3]
2-$CH_3OC_6H_4$-	51–52	I[63]
2,3-$(HO)_2C_6H_3$-	122	I[3]
2,3-$OCO_2C_6H_3$-	93	I[3]
C_6H_4-1,3-di-	69–70	I[59]
C_6H_4-1,4-di-	120–121	I[59]
2-HOC_6H_3-1,3-di-	127	II[45]
2-$CH_3COOC_6H_3$-1,3-di-	137	II[65]
2-$CH_3OC_6H_3$-1,3-di-	109	II[45]
C_6H_3-1,2,3-tri-	140–142	I[59]
C_6H_3-1,3,5-tri-	115–117	I[45, 59]
2-$CH_3C_6H_4$-	39–40, 35–36	I[63, 64]
3-$CH_3C_6H_4$-	45	I[64]
4-$CH_3C_6H_4$-	43	I[64]
2-$Cl_2CHC_6H_4$-	73	II[65]
2,3-$Cl(CH_3)C_6H_3$-	58–58.5	I[6]
4,3-$Cl(CH_3)C_6H_3$-	66	I[6]
6,3-$Cl(CH_3)C_6H_3$-	99	I[6]
2,4,3-$Cl_2(CH_3)C_6H_2$-	69.5	I[6]
2,6,3-$Cl_2(CH_3)C_6H_2$-	70	I[6]
4,6,3-$Cl_2(CH_3)C_6H_2$-	86	I[3]
2,4,6,3-$Cl_3(CH_3)C_6H$-	121	I[6]
2,3-$Br(CH_3)C_6H_3$-	70–71	I[5]
4,3-$Br(CH_3)C_6H_3$-	79–80	I[6]

TABLE XXI (*Continued*)

Aryl Group	M.P. (B.p. [mm.]), °C.	Prep. Method and Reference
A. Aryl Benzenesulfonates (Continued)		
2,5-Br$(CH_3)C_6H_3$-	92–93	I[6]
2,4,3-$Br_2(CH_3)C_6H_2$-	92–92.5	I[5]
2,6,3-$Br_2(CH_3)C_6H_2$-	94–95	I[6]
2,4,6,3-$Br_3(CH_3)C_6H$-	117–117.5	I[6]
2,4,6-$(C_6H_5CONH)(Cl)(CH_3)C_6H_2$-	116–117	I[6]
2,4,6-$(CH_3CONH)(Br)(CH_3)C_6H_2$-	116–116.5	I[6]
2,4,6-$(C_6H_5CONH)(Br)(CH_3)C_6H_2$-	114	I[6]
2,5-HO$(CHO)C_6H_3$-	147	I[67]
2,6-$CH_3O(CHO)C_6H_3$-	121	I[66]
4,2-$CH_3(CHO)C_6H_3$-	63	I[62]
2-$(COOH)C_6H_4$-	128–130	I,[62] II[64]
2-$(COOCH_3)C_6H_4$-	41–42	I[62]
2-$(COOC_6H_5)C_6H_4$-	80–82	I[62]
3-$(COOH)C_6H_4$-	114–116	II[62]
4-$(COOH)C_6H_4$-	170	II[62]
2,6-$CH_3O(COOH)C_6H_3$-	195	II[62]
5-$(COOH)C_6H_2$-1,2,3-tri-	200–208	I[62]
2-$C_6H_5C_6H_4$-	66–68	I[1]
3-$C_6H_5C_6H_4$-	(273[16])	I[1]
4-$C_6H_5C_6H_4$-	104–105	I[6]
4-$(4\text{-}BrC_6H_4)C_6H_4$-	79–81	I,[10] II[10]
2,4-Br$(C_6H_5)C_6H_3$-	102–103	I[10]
2,6,4-$Br_2(C_6H_5)C_6H_2$-	145–147.5	I[10]
$(4\text{-}C_6H_4)_2$-di-	148	I[28]
4,2-$(4\text{-}CH_3OC_6H_4CO)(NH_2)C_6H_3$-	113.5–114.5	I[6]
$SO_2(C_6H_4\text{-}4\text{-})_2$-di-	131–132	I[70]
$C_{10}H_7$-2-	105–107	I[69]
$C_6H_4\overset{CHCH}{\overline{\qquad\qquad}}C_6H_3$-3-	105–107	I[71]
2,4,6-$(C_2H_5OCONH)(Br)(CH_3)C_6H_2$-	115–115.5	I[6]
2,4,6-$(C_6H_5SO_2NH)(Br)(CH_3)C_6H_2$-	230	I[6]
2,4,6-$(2\text{-}C_{10}H_7SO_2NH)(Br)(CH_3)C_6H_2$-	126	I[6]
2,4-$CH_3O(CH_3)C_6H_3$-	Oil	I[63]
4-$(CH_3)_3CC_6H_4$-	70–71	I[7]
4-$C_2H_5(CH_3)_2CC_6H_4$-	(184–185[3])	I[7]
4-*n*-$C_3H_7(CH_3)_2CC_6H_4$-	(174–175[3])	I[7]
4-*iso*-$C_3H_7(CH_3)_2CC_6H_4$-	(178–179[3])	I[7]
4-$(C_2H_5)_2(CH_3)CC_6H_4$-	(183–184[3])	I[7]
2,5-$(CH_3)_2C_6H_3$-	51–52	I[62]
3,4-$(CH_3)_2C_6H_3$-	72–80	I[62]
2,5-$(CH_3)_2CH(CH_3)C_6H_3$-	55–56	I[69]
5,2-$(CH_3)_2CH(CH_3)C_6H_3$-	Oil	I[62]
2,4-$CH_3O(CH_2{=}CHCH_2)C_6H_3$-	Oil	I[62]
2-$(CHO)C_6H_4$-	55	I,[63] II[64]

TABLE XXI (*Continued*)

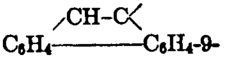
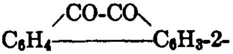
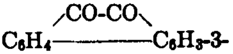
Aryl Group	M.P. (B.p. [mm.]), °C.	Prep. Method and Reference
	A. Aryl Benzenesulfonates (*Continued*)	
3-(CHO)C_6H_4-	Oil	II[64]
4-(CHO)C_6H_4-	82	II[64]
[4-(-CH=N-)C_6H_4-]$_2$-di-	167	II[64]
2,4-HO(CHO)C_6H_3-	110	I[67a]
2,4-CH_3O(CHO)C_6H_3-	69–70	I,[63] II[67b]
2,4-C_2H_5O(CHO)C_6H_3-	72	II[67c]
 $\overset{\diagup CH\text{-}C\diagdown}{C_6H_4\text{———}C_6H_4}$-9-	88.5	I[71]
 $\overset{\diagup CO\text{-}CO\diagdown}{C_6H_4\text{———}C_6H_3}$-2-	"Amorphous"	I[72]
 $\overset{\diagup CO\text{-}CO\diagdown}{C_6H_4\text{———}C_6H_3}$-3-	216–218	II[72]
$C_6H_4(CO)_2C_6H_2$-1,2-di-	182–184	I[73]
$C_6H_3(CO)_2C_6H_2$-1,2,7-tri-	182–186	I[73]
	B. Aryl p-Toluenesulfonates	
C_6H_5-	93, 94–95	I,[67] II[36]
2-ClC_6H_4-	74	I[13]
2-BrC_6H_4-	77–79, 76	I[1, 13]
3-BrC_6H_4-	52–54	I[1]
4-BrC_6H_4-	93–95	I[1]
2,4-$ClBrC_6H_3$-	114–115	I[23]
4,6,2-$Cl_2BrC_6H_2$-	82–83	I[68]
2,4-$Br_2C_6H_3$-	120	I[23]
2,5-$Br_2C_6H_3$-	109–110	I[23]
4,2,6-$ClBr_2C_6H_2$-	107–108	I[23]
2,4,6-$Br_3C_6H_2$-	113	I[26]
2-IC_6H_4-	73, 80	I,[16] II[77]
4-IC_6H_4-	99	I[17]
2-$(Cl_2I)C_6H_4$-	95–97	II[16]
4-$(Cl_2I)C_6H_4$-	115	II[17]
2-$O_2NC_6H_4$-	81.5	I[77, 78, 79]
3-$O_2NC_6H_4$-	112	I[15, 23]
4-$O_2NC_6H_4$-	97–97.5, 98	I,[25, 78, 80] II[76]
2-$NHOHC_6H_4$-	....	II[68]
4-$NHOHC_6H_4$-	104.3	II[36]
2-ONC_6H_4-	45 and 87.5	II[36]
4-ONC_6H_4-	143	II[36]
4,2-$Cl(NO_2)C_6H_3$-	74	I[23]
2,5-$Br(NO_2)C_6H_3$-	131.5–132.5	I[23]
3,2-$Br(NO_2)C_6H_3$-	136.5–137.5	I[23]
4,6,2-$Br_2(NO_2)C_6H_2$-	140	I[36]
2,6,4-$Br_2(NO_2)C_6H_2$-	128–129	I[36]

TABLE XXI (*Continued*)

Aryl Group	M.P. (B.p. [mm.]), °C.	Prep. Method and Reference
B. Aryl p-Toluenesulfonates (*Continued*)		
2,4,6,3-$Br_3(NO_2)C_6H$-	146–147	I[22]
2,4-$(NO_2)_2C_6H_3$-	121, 124	I[30, 81]
2,6-$(NO_2)_2C_6H_3$-	135, 138	I[21, 51]
4,2,6-$Cl(NO_2)_2C_6H_2$-	126	I[81, 90]
2,4,6-$Br(NO_2)_2C_6H_2$-	157	I[24]
4,2,6-$Br(NO_2)_2C_6H_2$-	136	I[31]
3,2,4,6-$ClBr(NO_2)_2C_6H$-	125	I[21]
4,2,6-$I(NO_2)_2C_6H_2$-	138	I[21]
2,4,6-$I(NO_2)_2C_6H_2$-	149	I[21]
3,2,4,6-$ClI(NO_2)_2C_6H$-	150	I[31]
2-$N_3C_6H_4$-	72	I,[82] II[82]
2-$H_2NC_6H_4$-	102	II[15]
3-$H_2NC_6H_4$-	98	II[15]
4-$H_2NC_6H_4$-	145	II[15]
4-$(CH_3)_2NC_6H_4$-	130	I[49]
4-$[(CH_3)_2NHCl]C_6H_4$-	188	II[49]
4-$(4\text{-}ClC_6H_4NH)C_6H_4$-	93–94	I[35]
2-$CH_3CONHC_6H_4$-	134	II[15]
2-$(1\text{-}C_{10}H_7CONH)C_6H_4$-	125	II[15]
2-$(2\text{-}C_{10}H_7CONH)C_6H_4$-	125	II[15]
2-$C_6H_5CH{=}NC_6H_4$-	98	II[15]
2-$[4\text{-}(CH_3)_2NC_6H_4CH{=}N]C_6H_4$-	135	II[15]
2-$[CH_3(C_6H_5)NCONH]C_6H_4$-	111–112	I[11]
2-$(4\text{-}CH_3C_6H_4SO_2NH)C_6H_4$-	143	I[15]
3-$C_6H_5CH{=}NC_6H_4$-	90	II[15]
4-$C_6H_5CH{=}NC_6H_4$-	165	II[15]
5,2-$Cl(NH_2)C_6H_3$-	112	II[15]
3,4-$Cl(2,4\text{-}Cl_2C_6H_3NH)C_6H_3$-	130.5	I[55]
3,5,4-$Cl_2(2,4\text{-}Cl_2C_6H_3NH)C_6H_2$-	126	I[55]
3,5,4-$Cl_2(2,4,6\text{-}Cl_3C_6H_2NH)C_8H_2$-	156.5	I[55]
2,3,5,4-$Cl_3(2,4,6\text{-}Cl_3C_6H_2NH)C_6H$-	141	I[55]
2,3,5,6,4-$Cl_4(2,4,6\text{-}Cl_3C_6H_2NH)C_6$-	141.5	I[55]
3,2-$Br(NH_2)C_6H_3$-	120–121	II[23]
2,5-$Br(NH_2)C_6H_3$-	135–136	II[82]
3,4-$Br(2,4\text{-}Br_2C_6H_3NH)C_6H_3$-	....	I[55]
3,5,4-$Br_2(2,4,6\text{-}Br_3C_6H_2NH)C_6H_2$-	210	I[55]
2,4,6,3-$Br_3(NH_2)C_6H$-	146–147	II[28]
5,3,4-$ClBr(2,4,6\text{-}ClBr_2C_6H_2NH)C_6H_2$-	185	I[55]
5,3,4-$ClBr(2,4,6\text{-}Cl_2BrC_6H_2NH)C_6H_2$-	174	I[55]
3,6,4-$ClBr(2,4\text{-}Cl_2C_6H_3NH)C_6H_2$-	114	I[35]
5,2-$Cl(CH_3CONH)C_6H_3$-	168	II[15]
3,2-$(NO_2)(NH_2)C_6H_3$-	136	I[22]
5,2-$(NO_2)(NH_2)C_6H_3$-	188	II[22]
3,2-$(NO_2)(CH_3CONH)C_6H_3$-	120	I[82]
5,2-$(NO_2)(CH_3CONH)C_6H_6$-	189	II[22]

TABLE XXI (*Continued*)

Aryl Group	M.P. (B.p. [mm.]), °C.	Prep. Method and Reference
	B. Aryl p-Toluenesulfonates (Continued)	
4,2-$(NO_2)(4\text{-}CH_3C_6H_4SO_2NH)C_6H_3$-	132	I[33]
4,3-$(NO_2)(4\text{-}CH_3C_6H_4SO_2NH)C_6H_3$-	114	I[32]
5,2-$(NO_2)(4\text{-}CH_3C_6H_4SO_2NH)C_6H_3$-	159	II[32]
2,4,3-$(NO_2)_2(C_6H_5NH)C_6H_2$-	151	I[48]
3,5,2-$(NO_2)_2(CH_3CONH)C_6H_2$-	205	I[33]
3,5,2-$(NO_2)_2(4\text{-}CH_3C_6H_4SO_2NH)C_6H_2$-	188	II[33]
4,6,3-$(NO_2)_2(4\text{-}CH_3C_6II_4SO_2NH)C_6H_2$-	158	I[33]
2-$CH_3OC_6H_4$-	85	I[80]
5,2-$(NO_2)(CH_3O)C_6H_3$-	145	I,[33] II[80]
2,4,3-$(NO_2)_2(OH)C_6H_2$-	126–127	I[48]
2,4,5-$(NO_2)_2(OH)C_6H_2$-	135	I[48]
4,6,2-$(NO_2)_2(CH_3O)C_6H_2$-	137–138	I[31]
2,5-$(NH_2)(OH)C_6H_3$-	....	II[33]
5,2-$(NH_2)(CH_3O)C_6H_3$-	151	II[33]
5,2-$(CH_3CONH)(CH_3O)C_6H_3$-	138–139	II[33]
4-$NaO_3SC_6H_4$-	....	I[12]
2-$CH_3C_6H_4$-	54–55	I[76]
3-$CH_3C_6H_4$-	51	I[64, 76]
4-$CH_3C_6H_4$-	69–70	I[64, 76]
2,3-$Cl(CH_3)C_6H_3$-	96	I[6]
4,3-$Cl(CH_3)C_6H_3$-	98, 96	I[6, 80]
6,3-$Cl(CH_3)C_6H_3$-	93–94, 98	I[6, 26]
2,4,3-$Cl_2(CH_3)C_6H_2$-	100–101	I[6]
2,6,3-$Cl_2(CH_3)C_6H_2$-	92–92.5	I[6]
4,6,3-$Cl_2(CH_3)C_6H_2$-	104–105	I[5]
2,4,6,3-$Cl_3(CH_3)C_6H$-	92–93	I[6]
2,3-$Br(CH_3)C_6H_3$-	85–85.5	I[5]
4,3-$Br(CH_3)C_6H_3$-	84–85	I[5]
6,3-$Br(CH_3)C_6H_3$-	72.5–73	I[5]
2,4-$Br(CH_3)C_6H_3$-	121	I[14]
2,4,3-$Br_2(CH_3)C_6H_2$-	89.5–90	I[5]
2,6,3-$Br_2(CH_3)C_6H_2$-	122–123	I[5]
2,4,6,3-$Br_3(CH_3)C_6H$-	113–114	I[5]
3,2-$(NO_2)(CH_3)C_6H_3$-	94	I[18]
4,2-$(NO_2)(CH_3)C_6H_3$-	123–124	I[80]
2,4,5-$(NO_2)_2(CH_3)C_6H_2$-	110–111	I[80]
2,3,5-$(NO_2)_2(CH_3)C_6H_2$-	....	I[48]
2,6,4-$(NO_2)_2(CH_3)C_6H_2$-	152	I[86, 79, 82]
4,6,2-$(NO_2)_2(CH_3)C_6H_2$-	167	I[80]
4,2,6,3-$Cl(NO_2)_2(CH_3)C_6H$-	125	I[21]
4-$(CH_3)_3CC_6H_4$-	109–110	I[7]
4-$C_2H_5(CH_3)_2CC_6H_4$-	54–55	I[7]
4-*n*-$C_3H_7(CH_3)_2CC_6H_4$-	(194–195[3])	I[7]
4-*iso*-$C_3H_7(CH_3)_2CC_6H_4$-	(187–188[3])	I[7]
4-$(C_2H_6)_2(CH_3)CC_6H_4$-	(188–189[3])	I[7]

TABLE XXI (*Continued*)

Aryl Group	M.P. (B.p. [mm.]), °C.	Prep. Method and Reference
B. Aryl p-Toluenesulfonates (Continued)		
3,5-$(CH_3)_2C_6H_3$-	83	I[53]
6,2,4-$(NO_2)(CH_3)_2C_6H_2$-	111–112	I[80]
3,5,2,4-$(NO_2)_2(CH_3)_2C_6H$-	110–111	I[80]
2,4,3,6-$(NO_2)_2(CH_3)_2C_6H$-	137	I[21]
4,6,2,5-$(NO_2)_2$(*iso*-C_3H_7)$(CH_3)C_6H$-	142	I[80]
2,4,3,6-$(NO_2)_2$(*iso*-C_3H_7)$(CH_3)C_6H$-	125	I[20]
4,2,6-$Cl(CH_2OH)_2C_6H_2$-	151	I[43]
4,2,6-$CH_3O(CH_2OH)_2C_6H_2$-	134	I[43]
4,2,6-$CH_3(CH_2OH)_2C_6H_2$-	132.5	I[88]
4,2,6-$C_6H_{11}(CH_2OH)_2C_6H_2$-	162–162.5	I[43]
2-$(CHO)C_6H_4$-	62, 66–68	II[64, 80]
3-$(CHO)C_6H_4$-	....	.....
4-$(CHO)C_6H_4$-	73–74	II[64]
2,3-$(NO_2)(CHO)C_6H_3$-	112	I[78]
2,5-$(NO_2)(CHO)C_6H_3$-	102	I[75]
4,3-$(NO_2)(CHO)C_6H_3$-	94	I[76]
4,2,3-$Cl(NO_2)(CHO)C_6H_2$-	155	I[78]
4,6,2,3-$Cl_2(NO_2)(CHO)C_6H$-	172	I[75]
2,4-$HO(CHO)C_6H_3$-	118	I[87a]
2,4-$CH_3O(CHO)C_3H_3$-	115	II[87b]
3,5,4-$CH_3O(HO)(CHO)C_6H_2$-	104	I[80]
3,5,4-$(CH_3O)_2(CHO)C_6H_2$-	122	II[88]
3,5,2-$(CH_3O)_2(CHO)C_6H_2$-	144	I[80]
4,2-$CH_3(CHO)C_6H_3$-	68–69	I[89]
6,2-$CH_3(CHO)C_6H_3$-	62	I[80]
4,2,6-$Cl(CHO)_2C_6H_2$-	123	II[43]
4,2,6-$CH_3O(CHO)_2C_6H_2$-	121.5	II[43]
4,2,6-$CH_3(CHO)_2C_6H_2$-	146.5	II[88]
2-$(COOH)C_6H_4$-	154–156	II[64]
3-$(COOH)C_6H_4$-	162	II[64]
4-$(COOH)C_6H_4$-	168–170	II[64]
2,4-$(NO_2)(COOCH_3)C_6H_3$-	86	I[21]
2,5-$(NO_2)(COOH)C_6H_3$-	160–162	II[76]
6,2,4-$Br(NO_2)(COOCH_3)C_6H_2$-	127	I[21]
3,4,6-$CH_3(NO_2)(COOCH_3)C_6H_2$-	93	I[21]
4,2,6-$CH_3(NO_2)(COOC_2H_5)C_6H_2$-	110	I[20]
2,4-$(NO_2)(CN)C_6H_3$-	139–141	I[81]
2,6,4-$(CH_3O)(NO_2)(CN)C_6H_2$-	104	I[81]
4,6,2-$CH_3(NO_2)(CN)C_6H_2$-	137–138	I[21]
2-$C_6H_5C_6H_4$-	64–66	I[1]
3-$C_6H_5C_6H_4$-	52–54	I[1]
4-$C_6H_5C_6H_4$-	178.5–179.5, 177	I[1, 43]
2,6,4-$Br_2(C_6H_5)C_3H_2$-	132	I[80]
4-[4-$(NO_2)C_6H_4]C_6H_4$-	156–158	I,[80] II[82]
4,2-$(NO_2)[(NO_2)C_6H_4]C_6H_3$-	147–148	I[82]

TABLE XXI (*Continued*)

Aryl Group	M.P. (B.p. [mm.]), °C.	Prep. Method and Reference
	B. Aryl p-Toluenesulfonates (Continued)	
2,4,6-$(NO_2)_2(C_6H_5)C_6H_2$-	147–148	I[85]
2,5-$(4\text{-}CH_3C_6H_4)(CH_3)C_6H_3$-	130	I[27]
$(C_6H_4)_2$-2,2′-di-	187–188	I[28]
$[3,5\text{-}(NO_2)_2C_6H_2]_2$4,4′-di-	267 (dec.)	I[28]
2,5-$(C_6H_5)_2C_6H_3$-	102	I[85]
$SO_2(C_6H_4)_2$-4,4′-di-	171–172	I[70]
$C_{10}H_7$-1-	83–84	I[38]
$C_{10}H_7$-2-	125	I[80]
2,4-$(NO_2)_2C_{10}H_5$-1-	159.5	I[84]
1-$H_2NC_{10}H_6$-3-	137	II[38]
1-$(CONH_2)C_{10}H_6$-3-	210 (dec.)	I[38]
2,1-$H_2N(SO_3Na)C_{10}H_5$-5-	....	I[40]
1,4-$H_2N(4\text{-}CH_3C_6H_4SO_2)C_{10}H_5$-2-	....	II[43]
$C_{10}H_6$-2,6-di-	150	I[80]
$C_{13}H_9$-2-(fluorenyl)	....	I[37]
7-$(NO_2)C_{13}H_8$-2-	....	II[37]
	C. Aryl p-Bromobenzenesulfonates	
C_6H_5-	115.5	I[34]
2-BrC_6H_4-	125	I[34]
2,4,6-$Br_3C_6H_2$-	139–140	I[34]
2-$O_2NC_6H_4$-	97–98	I[34]
3-$O_2NC_6H_4$-	108–109	I[34]
4-$O_2NC_6H_4$-	112	I[34]
2-$CH_3OC_6H_4$-	103–104	I[34]
2-$CH_3C_6H_4$-	78–79	I[34]
3-$CH_3C_6H_4$-	69–70	I[34]
4-$CH_3C_6H_4$-	100	I[34]
6,2,4-$Br(4\text{-}BrC_6H_4SO_2NH)(CH_3)C_6H_2$-	130–131	I[4]
2,5-$(iso\text{-}C_3H_7)(CH_3)C_6H_3$-	103.5	I[34]
2-$C_6H_5C_6H_4$-	69–70	I[34]
3-$C_6H_5C_6H_4$-	102.5–103.5	I[34]
4-$C_6H_5C_6H_4$-	185–186	I[34]
$(C_6H_4)_2$-4,4′-di-	201–202	I[28]
$C_{10}H_7$-1-	104	I[34]
$C_{10}H_7$-2-	151–152	I[34]
	D. Aryl Nitrobenzenesulfonates	
(1) *o*-$O_2NC_6H_4SO_3H$ esters		
C_6H_5-	57	I[106]
2,4,6-$Cl_3C_6H_2$-	142	I[107]
2-$CH_3C_6H_4$-	59	I[106]
2-$C_6H_5C_6H_4$-	72–73	I[34]
3-$C_6H_5C_6H_4$-	69–70	I[34]
4-$C_6H_5C_6H_4$-	138–139	I[34]
$(C_6H_4)_2$-4,4′-di-	191–192	I[28]

TABLE XXI (*Continued*)

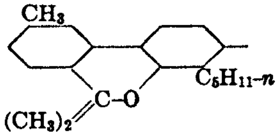
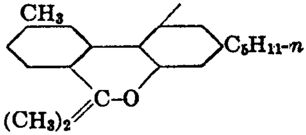
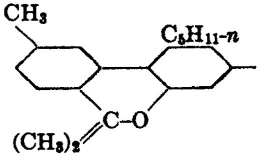
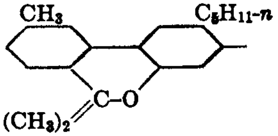
Aryl Group	M.P. (B.p. [mm.]), °C.	Prep. Method and Reference
D. Aryl Nitrobenzenesulfonates (*Continued*)		
(2) *m*-$O_2NC_6H_4SO_3H$ derivatives		
2,4,6-$Cl_3C_6H_2$-	90–91	II[60]
2,4,6-$Br_3C_6H_2$-	151	II[60]
4-$O_2NC_6H_4$-	....	II[74]
2,4-$(NO_2)_2C_6H_3$-	115–116	II[58]
2-$C_6H_5C_6H_4$-	130–131	I[46]
3-$C_6H_5C_6H_4$-	111–112	I[46]
4-$C_6H_5C_6H_4$-	143–144	I[46]
$(C_6H_4)_2$-4,4′-di-	216–217	I[28]
$C_{10}H_7$-1-	....	I[46]
4-$O_2NC_{10}H_6$-1-	135	II[46]
8-$O_2NC_{10}H_6$-1-	166	II[46]
4,5-$(NO_2)_2C_{10}H_5$-1-	174	II[46]
4,8-$(NO_2)_2C_{10}H_5$-1-	165	II[46]
$C_{10}H_7$-2-	....	II[46]
1-$O_2NC_{10}H_6$-2-	176	I[46]
4-$O_2NC_{10}H_6$-2-	149	I[46]
5-$O_2NC_{10}H_6$-2-	166	II[46]
8-$O_2NC_{10}H_6$-2-	144–146	II[46]
4,5-$(NO_2)_2C_{10}H_5$-2-	212	II[46]
1,5-$(NO_2)_2C_{10}H_5$-2-	153	II[46]
1,8-$(NO_2)_2C_{10}H_5$-2-	201	II[46]
	122.5–123	I[41]
	127–129	I[41]
	118	I[41]
	100–101	I[41]
(3) *p*-$O_2NC_6H_4SO_3H$ esters		
C_6H_5-	114	I[37]

TABLE XXI (*Continued*)

Aryl Group	M.P. (B.p. [mm.]), °C.	Prep. Method and Reference
D. Aryl Nitrobenzenesulfonates (Continued)		
3-$O_2NC_6H_4$-	133	I[47]
4-$O_2NC_6H_4$-	156	I[47]
4-$CH_3C_6H_4$-	106	I[47]
2,4-$(NO_2)(CH_3)C_6H_3$-	136(?)	I[47]
3,4-$(NO_2)(CH_3)C_6H_3$-	116(?)	I[47]
2-$C_6H_5C_6H_4$-	110–111	I[44]
3-$C_6H_5C_6H_4$-	97–98	I[44]
4-$C_6H_5C_6H_4$-	148.5–149.5	I[44]
$(C_6H_4)_2$-4,4′-	231	I[28]
E. Miscellaneous Aryl Sulfonates		
3,4-$Cl_2C_6H_3SO_3C_6H_2$(3,4-$Cl_2C_6H_3SO_2NH$)-$(CH_3)Br$-2,4,6	114	I[4]
2,5-$Cl(NO_2)C_6H_3SO_3C_6H_5$	92–93	I[54]
2,5-$Cl(NO_2)C_6H_3SO_3C_6H_2(CH_3OCONH)$-$(CH_3)Br$-2,4,6	151	I[4]
2,5-$Cl(NO_2)C_6H_3SO_3C_6H_2$[2,5-$Cl(NO_2)$-$C_6H_3SO_2NH](CH_3)Br$-2,4,6	221	I[4]
4,2-$Cl(NO_2)C_6H_3SO_3C_6H_5$	82	I[106]
4,2-$Cl(NO_2)C_6H_3SO_3C_6H_4Cl$-2	....	I[106]
4,2-$Cl(NO_2)C_6H_3SO_3C_6H_4Cl$-4	99	I[106]
4,2-$Cl(NO_2)C_6H_3SO_3C_6H_3Cl_2$-2,5	130	I[106]
4,2-$Cl(NO_2)C_6H_3SO_3C_6H_2Cl_3$-2,4,6	128	I[106]
2,5-$I(NO_2)C_6H_3SO_3C_6H_5$	128–129	I[54]
4,2-$Cl(NO_2)C_6H_3SO_3C_6H_4CH_3$-4	97	I[106]
2,5-$Cl(NH_2)C_6H_3SO_3C_6H_5$	75–76	II[54]
2-$NH_2C_6H_4SO_3C_6H_2Cl_3$-2,4,6	153	II[107]
4-(4-$HOC_6H_4SO_3)C_6H_4SO_3H$	....	I[93]
4-(4-$CH_3COOC_6H_4SO_3)C_6H_4SO_3H$	....	II[93]
3,5,4-$(OH)_2$[3,4,5-$(OH)_3C_6H_2SO_3$]-$C_6H_2SO_3H$	....	I[99, 101]
3,5,4-$(CH_3COO)_2$[3,4,5-$(CH_3COO)_3$-$C_6H_2SO_3]C_6H_2SO_3H$	....	II[99]
2,6,4-$(OH)_2$[2,4,6-$(OH)_3C_6H_2SO_3$]-$C_6H_2SO_3H$	....	I[99]
2-$(COOC_6H_5)C_6H_4SO_3C_6H_5$	117.5–118.5	I[94,95,96,97]
2-$(CONH_2)C_6H_4SO_3C_6H_5$	95	I[98]
5,2-$(NO_2)(COOC_6H_5)C_6H_3SO_3C_6H_5$	118–119	I[98, 99]
5,2-$(NO_2)(COOC_6H_4NO_2$-2$)C_6H_3SO_3$-$C_6H_4NO_2$-2	164	I[98]
5,2-$(NO_2)(COOC_6H_4NO_2$-4$)C_6H_3SO_3$-$C_6H_4NO_2$-4	152	I[98]
5,2-$(NO_2)(COOC_6H_4CH_3$-4$)(C_6H_3SO_3$-$C_6H_4CH_3$-4	94–95	I[98, 99]
5,2-$(NO_2)(COOC_{10}H_7$-2$)C_6H_3SO_3C_{10}H_7$-2	134	I[98]

TABLE XXI (*Continued*)

Aryl Group	M.P. (B.p. [mm.]), °C.	Prep. Method and Reference
E. Miscellaneous Aryl Sulfonates (*Continued*)		
$4,3\text{-}(OH)(COOC_6H_5)C_6H_3SO_3C_6H_5$	172–173	I[100]
$4,3\text{-}(OH)(COOC_{10}H_7\text{-}2)C_6H_3SO_3C_{10}H_7\text{-}2$	....	I[100]
$4,3\text{-}(OH)(COOC_6H_4OCH_3\text{-}2)C_6H_3SO_3C_6H_4\text{-}OCH_3\text{-}2$	112–113	I[100]
$3,4\text{-}Br(CH_3)C_6H_3SO_3C_6H_2Br_3\text{-}2,4,5$	107–108	II[23]
$2\text{-}CH_3C_6H_4SO_3C_6H_5$	52	I[74]
$2\text{-}CH_3C_6H_4SO_3C_6H_4NO_2\text{-}2$	131–134	I[67]
$2\text{-}CH_3C_6H_4SO_3C_6H_4CH_3\text{-}2$	50–51	I[64]
$2\text{-}CH_3C_6H_4SO_3C_6H_4CH_3\text{-}3$	60	I[64]
$2\text{-}CH_3C_6H_4SO_3C_6H_4CH_3\text{-}4$	70–71	I[64]
$2\text{-}CH_3C_6H_4SO_3C_6H_4CHO\text{-}2$	79–80	II[64]
$2\text{-}CH_3C_6H_4SO_3C_6H_4CHO\text{-}3$	65–66	II[64]
$2\text{-}CH_3C_6H_4SO_3C_6H_4CHO\text{-}4$	61–62	II[64]
$2\text{-}CH_3C_6H_4SO_3C_6H_4COOH\text{-}2$	118–120	II[64]
$2\text{-}CH_3C_6H_4SO_3C_6H_4COOH\text{-}3$	144–146	II[64]
$2\text{-}CH_3C_6H_4SO_3C_6H_4COOH\text{-}4$	168–170	II[64]
$5,2\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H_5$	64	I[102]
$5,2\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H_4NO_2\text{-}4$	195	II[74]
$3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H_5$	59–60	I[76]
$3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H_4NO_2\text{-}4$	113–114	I,[80] II[60]
$3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H_2(NO_2)Br_2\text{-}5,2,4$	122–123	II[26]
$3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H_2(NO_2)\text{-}BrCl\text{-}5,4,2$	107–108	II[23]
$3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H(NO_2)\text{-}BrCl_2\text{-}3,6,2,4$	122–122.5	II[23]
$3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H(NO_2)\text{-}BrCl_2\text{-}5,6,2,4$	134–135	II[23]
$3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H_4CH_3\text{-}2$	68–69	I[76]
$3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H_4CH_3\text{-}3$	63	I[76]
$3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H_4CH_3\text{-}4$	95	I[76]
$3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H_3(CH_3)NO_2\text{-}2,4$	108–109, 120–121	II[19, 76]
$3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H_2(CH_3)(NO_2)_2\text{-}2,4,5$	125–126	II[19]
$3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H(CH_3)_2(NO_2)_2\text{-}2,4,5,6$	140–141	II[23]
$3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H(CH_3)_2(NO_2)_2\text{-}3,5,2,4$	148–149	II[23]
$3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H_2[3,4\text{-}(NO_2)\text{-}(CH_3)C_6H_3SO_2NH](CH_3)Br\text{-}2,4,6\text{-}$	175–176	I[4]
$1,3\text{-}[3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3]_2C_6H_4$	136	I[80]
$1,3,4\text{-}[3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3]_2(NO_2)\text{-}C_6H_3$	105	II[23]
$3,4\text{-}(NH_2)(CH_3)C_6H_3SO_3C_6H_2(NH_2)Br_2 5,2,4$	174–175	II[23]
$3,6,4\text{-}(NO_2)(COOC_6H_5)(CH_3)C_6H_2SO_3C_6H_5$	123	I[103]

TABLE XXI (*Continued*)

Aryl Group	M.P. (B.p. [mm.]), °C.	Prep. Method and Reference
E. Miscellaneous Aryl Sulfonates (Continued)		
$3,2,5\text{-}(NO_2)(CH_3)_2C_6H_2SO_3C_6H_5$	117–118	I^{104}
$3,2,5\text{-}(NO_2)(CH_3)_2C_6H_2SO_3C_6H_4CH_3\text{-}2$	66–67	I^{105}
$3,2,5\text{-}(NO_2)(CH_3)_2C_6H_2SO_3C_6H_4CH_3\text{-}3$	71.5–72	I^{105}
$3,2,5\text{-}(NO_2)(CH_3)_2C_6H_2SO_3C_6H_4CH_3\text{-}4$	93.5–94.5	I^{105}
$4,2,5\text{-}(NO_2)(CH_3)_2C_6H_2SO_3C_6H_5$	120–120.5	I^{104}
$4,2,5\text{-}(NO_2)(CH_3)_2C_6H_2SO_3C_6H_4CH_3\text{-}2$	99–100	I^{105}
$4,2,5\text{-}(NO_2)(CH_3)_2C_6H_2SO_3C_6H_4CH_3\text{-}3$	110–111	I^{105}
$4,2,5\text{-}(NO_2)(CH_3)_2C_6H_2SO_3C_6H_4CH_3\text{-}4$	117.5–118.5	I^{105}
$6,2,5\text{-}(NO_2)(CH_3)_2C_6H_2SO_3C_6H_6$	83–83.5	I^{104}
$6,2,5\text{-}(NO_2)(CH_3)_2C_6H_2SO_3C_6H_4CH_3\text{-}2$	151.5–152	I^{105}
$6,2,5\text{-}(NO_2)(CH_3)_2C_6H_2SO_3C_6H_4CH_3\text{-}3$	107.5–108	I^{105}
$6,2,5\text{-}(NO_2)(CH_3)_2C_6H_2SO_3C_6H_4CH_3\text{-}4$	76–77	I^{105}
cis$[4,2\text{-}(NO_2)(SO_3C_6H_5)C_6H_3CH{=}]_2$	172	I,^{102} II^{102}
trans$[4,2\text{-}(NO_2)(SO_3C_6H_6)C_6H_3CH{=}]_2$	192–192.5	I,^{102} II^{102}
$3\text{-}C_6H_6SO_2C_6H_4SO_3C_6H_5$	106	I^{106}
$1\text{-}C_{10}H_7SO_3C_6H_5$	75	I^{74}
$2\text{-}C_{10}H_7SO_3C_6H_5$	98–99	I^{74}
$2\text{-}C_{10}H_7SO_3C_6H_2(CH_3)(NHSO_2C_6H_5)Br\text{-}4,2,6$	123	I^{4}
$2\text{-}C_{10}H_7SO_3C_6H_2(CH_3)(NHSO_2C_{10}H_7\text{-}2)(CH_3)Br\text{-}2,4,6$	141–142	I^{4}
$6,2\text{-}(OH)C_{10}H_6SO_3C_6H_5$	131	I^{23}

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[1] Hazlet, *J. Am. Chem. Soc.*, **59**, 287 (1937).

[2] Wacek and Travnicek, *Österr. Chem. Ztg.*, **42**, 281 (1939).

[3] Pollard and Amundsen, *J. Am. Chem. Soc.*, **57**, 357, 1536 (1935).

[4] Raiford and Gross, *ibid.*, **53**, 3420 (1931).

[5] Huston and Peterson, *ibid.*, **55**, 3879 (1933).

[6] Huston and Chen, *ibid.*, **55**, 4214 (1933).

[7] Huston and Hsieh, *ibid.*, **58**, 439 (1936).

[8] Huston and Hutchinson, *ibid.*, **54**, 1504 (1932).

[9] Raiford and Lankelma, *ibid.*, **47**, 1111 (1925).

[10] Haslet, *ibid.*, **59**, 1087 (1937).

[11] Raiford and Alexander, *J. Org. Chem.*, **5**, 300 (1940).

[12] Doherty, Stein, and Bergmann, *J. Biol. Chem.*, **135**, 487 (1940).

[13] Bennett, Brooks, and Glasstone, *J. Chem. Soc.*, 1821 (1935).

[14] Kermack and Spragg, *ibid.*, 2946 (1932).

[15] Bell, *ibid.*, 1981 (1930).

[16] Buchan and McCombie, *ibid.*, 137 (1931).

[17] Matheson and McCombie, *ibid.*, 1103 (1931).

[18] Jones and Robertson, *ibid.*, 1689 (1932).

[19] Curd and Robertson, *ibid.*, 1166 (1933).

[20] Sané, Chakravarty, and Parmanick, *J. Indian Chem. Soc.*, 9, **55** (1932).

[21] Sané and Joshi, *ibid.*, 9, 59 (1932).

[22] Fox and Turner, *J. Chem. Soc.*, 1853 (1930).

[23] Henley and Turner, *ibid.*, 928 (1930).

[24] Sané and Joshi, *ibid.*, **125**, 2481 (1924).

[25] Baudisch and Karseff, *Ber.*, **50**, 328 (1917).

[26] Borsche and Feske, *Ber.*, **59B**, 683 (1926).

[27] Marler and Turner, *J. Chem. Soc.*, 266 (1937).

[28] Haslet, *J. Am. Chem. Soc.*, 61, 1921 (1939).

[29] Gibson, *J. Chem. Soc.*, 1424 (1926).

[30] Freudenberg and Markert, *Ber.*, **58B**, 1753 (1925).

[31] Borsche, Löwenstein, and Quast, *Ber.*, **50**, 1339 (1917).

[32] Bell, *J. Chem. Soc.*, 2343 (1931).

[33] Head and Robertson, *ibid.*, 1241 (1931).

[34] Sekera, *J. Am. Chem. Soc.*, **55**, 421 (1933).

[35] Borsche and Scholten, *Ber.*, **50**, 596 (1917).

[36] Klaus and Baudisch, *Ber.*, **51**, 1228 (1918).

[37] Ruíz, Anales asoc. quím. argentina, **16**, 170 (1928); *C.A.*, **23**, 4691 (1929).

[38] Bell and Robinson, *J. Chem. Soc.*, 1127 (1927).

[39] Challenor and Ingold, *ibid.*, **123**, 2066 (1923).

[40] Bucherer and Wahl, *J. prakt. Chem.*, [2] **102**, 129 (1921).

[41] Adams, Cain, and Baker, *J. Am. Chem. Soc.*, **62**, 2201 (1940); Adams, Pease, Clark, and Baker, *ibid.*, **62**, 2198 (1940).

[42] Bradley and Robinson, *J. Chem. Soc.*, 1484 (1934).

[43] Zinke, Hanus, Ziegler, Sperk, Troger, and Weinhardt, *J. prakt. Chem.*, **152**, 126 (1939).

[44] Hazlet, *J. Am. Chem. Soc.*, **60**, 399 (1938).

[45] von Wacek and Schöpfer, *Österr. Chem. Ztg.*, **40**, 63 (1937).

[46] Bell, *J. Chem. Soc.*, 286 (1933); 2734 (1932).

[47] Bell, *ibid.*, 2770 (1928).

[48] Borsche and Feske, *Ber.*, 61B, 690 (1928).

[49] Slotta and Behnisch, *J. prakt. Chem.*, [2] **135**, 225 (1932).

[50] Sané and Joshi, *J. Indian Chem. Soc.*, **5**, 299 (1928).

[51] Kubota, *J. Chem. Soc. Japan*, **53**, 404 (1932).

[52] Bell and Kenyon, *J. Chem. Soc.*, 3044 (1926).

[53] Rowe, Bannister, Seth, and Storey, *J. Soc. Chem. Ind.*, **49**, 469 (1930).

[54] Leslie and Turner, *J. Chem. Soc.*, 2021 (1932)

[55] Bradfield, Cooper, and Orton, *J. Chem. Soc.*, 2854 (1927).

[56] Karrer and Helfenstein, *Helv. Chim. Acta*, **10**, 789 (1927).

[57] Otto, *Ber.*, **19**, 1832 (1886).

[58] Schiaparelli, *Gazz. chim. ital.*, **11**, 66 (1881).

[59] Georgescu, *Ber.*, **24**, 416 (1891).

[60] Minovici, *Bul. Soc. Stiinte, Bucuresci*, **2**, 131; Beilstein's "Handbuch," Fourth Edition, Vol. II, p. 31.

[61] Kastle and Speyer, *Am. Chem. J.*, **27**, 40 (1902).

[62] Wohlleben, *Ber.*, **42**, 4375 (1909).

[63] Georgescu, *Bul. Soc. Stiinte, Bucuresci*, 8, 669; *Chem. Zentr.*, I, 543 (1900).

[64] Badische Anilin- und Sodafabrik, German pat., 162,322, *ibid.*, II, 726 (1905).

[65] Raschig, German pat., 233,631, *ibid.*, I, 1388 (1911); *Frdl.*, **10**, 163.

[66] Vorländer, *Ber.*, **39**, 807 (1906).

[67] (*a*) Chem. Fabr. Schering, German pat., 76,493, *Chem. Zentr.*, II, 886 (1894). (*b*) German pat., 80,498, *Frdl.*, **4**, 1284. (*c*) German pat., 81,352, *Frdl.*, **4**, 1285.

[68] Rupp and Linck, *Arch. Pharm.*, **253**, 36 (1915).

[69] A.-G. für Anilinfabrik, German pat., 185,547, *Chem. Zentr.*, II, 863 (1907).

[70] Otto, *J. prakt. Chem.*, [2] **47**, 373 (1893).

[71] Werner, *Ann.*, **321**, 292 (1902).

[72] Werner, *Ann.*, **322**, 163 (1902).

[73] Georgescu, *Bul. Soc. Stiinte, Bucuresci*, **1**, 213.

[74] Gilliard, Monnet, and Cartier, German pat., 91,314, *Frdl.*, **4**, 40.

[75] Friedländer and Schenck, *Ber.*, **47**, 3046 (1914).

[76] Reverdin and Crépieux, *Bull. soc. chim.*, [3] **27**, 745 (1902).

[77] Ullmann and Lowenthal, *Ann.*, **332**, 64 (1904).

[78] Bamberger and Rising, *Ber.*, **34**, 241 (1901).

[79] Ullmann and Nádai, *Ber.*, **41**, 1871 (1908).

[80] Reverdin and Crépieux, *Bull. soc. chim.*, [3] **25**, 1044 (1901).

[81] Ullmann, German pat., 194,951, *Chem. Zentr.*, I, 1115 (1908).

[82] Forster and Fierz, *J. Chem. Soc.*, 91, 1354 (1907).

[83] Bayer and Co., German pat., 278,091, *Chem. Zentr.*, II, 965 (1914); *Frdl.*, **12**, 178.

[84] Ullmann and Bruck, *Ber.*, **41**, 3933 (1908).

[85] Fichter and Walter, *Ber.*, **42**, 4311 (1909).

[86] Ullmann and Brittner, *Ber.*, **42**, 2546 (1909).

[87] Baudisch, Pistor, and Silberblatt, *Ber.*, **49**, 193 (1916).

[88] Baudisch and Karseff, *Ber.*, **45**, 1170 (1912).

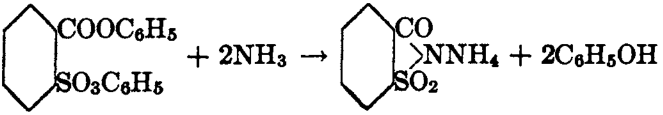
[89] Misslin and Bau, *Helv. Chim. Acta*, **2**, 298 (1919).
[90] Ullmann and Sané, *Ber.*, **44**, 3736 (1911).
[91] Borsche and Fiedler, *Ber.*, **46**, 2122 (1913).
[92] A.-G. für Anilinfabrik, German pat., 240,038, *Chem. Zentr.*, *II*, 1565 (1911); *Frdl.*, **10**, 178.
[93] Schiff, *Ann.*, **178**, 171 (1875).
[94] List and Stein, *Ber.*, **31**, 1662 (1898).
[95] Remsen and Humphreys, *Am. Chem. J.*, **30**, 294 (1903).
[96] Remsen and Saunders, *ibid.*, **17**, 352 (1895).
[97] Remsen and McKee, *ibid.*, **18**, 799 (1896).
[98] Henderson, *ibid.*, **25**, 11 (1901).
[99] Chambers, *ibid.*, **30**, 374 (1903).
[100] Cohn, *J. prakt. Chem.*, [2] **61**, 546 (1900).
[101] Anschütz, *Ann.*, **415**, 87 (1918).
[102] Green, Marsden, and Scholefield, *J. Chem. Soc.*, **85**, 1432 (1904).
[103] Karslake and Bond, *J. Am. Chem. Soc.*, **38**, 1348 (1916).
[104] Karslake and Huston, *ibid.*, **36**, 1252 (1914).
[105] Huston, *ibid.*, **37**, 2120 (1915).
[106] Otto, *Ber.*, **19**, 2421 (1886).
[107] Tozer and Smiles, *J. Chem. Soc.*, 2052 (1938).
[108] French pat., 821,551, *C.A.*, **32**, 3973 (1938).

Reactions and Uses. The behavior of aryl sulfonates toward hydrolytic agents is in strong contrast with that of the alkyl esters. Phenyl benzenesulfonate is hydrolyzed but slowly by boiling aqueous potassium hydroxide.[59] However, sodium ethoxide in alcohol reacts readily with phenyl *p*-toluenesulfonate at ordinary temperatures to give phenetole; this transformation probably occurs in two stages.[60]

$$p\text{-}C_7H_7SO_3C_6H_5 + C_2H_5ONa \rightarrow p\text{-}C_7H_7SO_3C_2H_5 + C_6H_5ONa$$

$$p\text{-}C_7H_7SO_3C_2H_5 + C_6H_5ONa \rightarrow C_6H_5OC_2H_5 + p\text{-}C_7H_7SO_3Na$$

Phenyl benzenesulfonate reacts only slowly with alcoholic ammonia [59] at 200°. When phenyl *p*-toluenesulfonate is cleaved by ammonia or hydrazine the products are phenol and the sulfonamide or hydrazide rather than aniline or phenylhydrazine.[61] Aqueous ammonia under pressure at 125° converts diphenyl *o*-sulfobenzoate into the ammonium salt of saccharin.[62]



Negatively substituted aryl sulfonates hydrolyze or cleave with considerable ease. Thus 2,4-dinitrophenyl *p*-toluenesulfonate is hydrolyzed by 10% aqueous sodium carbonate or aqueous ammonia to the dinitrophenol. Ammonia in boiling nitrobenzene on the other hand yields 2,4-dinitroaniline as well as ammonium *p*-toluenesulfonate and *p*-toluenesulfonamide.[63a] Heating with pyridine produces 2,4-dinitrophenylpyridinium *p*-toluenesulfonate. Aniline and sodium acetate convert *o*-nitrophenyl *p*-toluenesulfonate into *o*-nitrodiphenylamine. Similar esters having a *para* azo group also react with aniline.[63b] A similar reaction occurs when the di-*p*-toluenesulfonate of 3,3′,5,5′-tetranitro-4,4′-dihydroxybiphenyl is boiled with aniline.[64] A nitro group in the sulfonic acid ring does not appear greatly to facilitate cleavage since heating an aryl 4-chloro-3-nitrobenzenesulfonate with ammonia replaces the chlorine by an amino group without hydrolysis of the ester.[65]

When pyrogallol tribenzenesulfonate is allowed to stand at 25° with liquid ammonia under pressure[66] the middle ester group is removed while with hydrazine complete decomposition to pyrogallol and phenyl sulfide occurs.

It has been shown that many aryl sulfonates are readily cleaved by piperidine[67] with amide formation. If two nitro groups are present

$$3,4\text{-}Cl(CH_3)C_6H_3SO_3C_6H_2Cl_3\text{-}2,4,5 + C_5H_{10}NH \rightarrow 3,4\text{-}Cl(CH_3)C_6H_3SO_2NC_5H_{10} + 2,4,5\text{-}Cl_3C_6H_2OH$$

in the sulfonic acid nucleus the reaction takes another course.[68]

$$2,4\text{-}(NO_2)_2C_6H_3SO_3C_6H_4CH_3\text{-}4 + 2C_5H_{10}NH \rightarrow 4\text{-}CH_3C_6H_4OSO_3H_2NC_5H_{10} + 2,4\text{-}(NO_2)_2C_6H_3NC_5H_{10}$$

Treatment of 2,6-dinitro-4-methylphenyl *p*-toluenesulfonate with sodium phenoxide gives phenyl *p*-toluenesulfonate rather than an aryl ether.[69]

Hydrolysis of aryl sulfonates occurs less readily with acids[59] than with bases. Heating *p*-tolyl benzenesulfonate with anhydrous hydrogen fluoride at 100° rearranges it to 2-hydroxy-5-methylphenyl phenyl sulfone.[70] Diphenyl *o*-sulfobenzoate hydrolyzes to *o*-sulfobenzoic acid[62] when heated with concentrated hydrochloric acid at 200°. Pyrogallol tribenzenesulfonate is unaffected by hydrochloric acid at 170° or by boiling hydrobromic or hydriodic acid.[66]

There is little reaction between alkylmagnesium halides and aryl sulfonates unless drastic reaction conditions are used[71] but with the aryl Grignard reagents cleavage of the aryl sulfonate occurs easily

$$p\text{-}CH_3C_6H_4SO_3C_6H_5 + C_6H_5MgBr \rightarrow p\text{-}CH_3C_6H_4SO_2C_6H_5 + C_6H_5OMgBr$$

with sulfone formation if the reaction is carried out in boiling toluene. The yield of sulfone isolated varied from 43 to 82% for several arylmagnesium bromides.[71,72] It has been claimed[73] that a second reaction occurs to a small extent.

$$C_6H_5SO_3Ar + Ar'MgX \rightarrow C_6H_5SO_3MgX + (Ar\text{—} + Ar'\text{—})$$

The introduction of substituents into aryl sulfonates occurs less readily than for any other phenol derivative. For example, the relative rates of chlorination under certain conditions for phenyl benzoate and phenyl benzenesulfonate[74] are 0.00203 and 0.00013 respectively. The directive influence of the phenolic oxygen is so reduced in *p*-xenyl benzenesulfonate and *p*-toluenesulfonate that bromination[75] and nitration[76] occur in the second benzene ring.

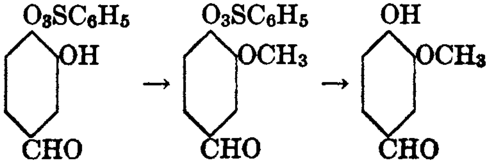
$$4\text{-}C_6H_5C_6H_4O_3SC_6H_5 + Br_2 \rightarrow 4\text{-}(4\text{-}BrC_6H_4)C_6H_4O_3SC_6H_5 + HBr$$

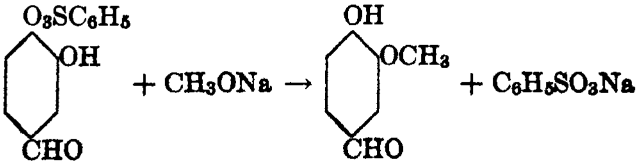
According to patent claims[77] it is possible to dichlorinate *o*-tolyl benzenesulfonate in the side chain without bringing about nuclear substitution. In the nitration of phenyl benzenesulfonate the introduction of nitro groups follows the sequence shown in the equations.[78] In the nitration of phenyl *p*-toluenesulfonate[79] the second nitro group enters the sulfonic acid nucleus. The yields in these nitrations are exceptionally high.[80]

$$C_6H_5SO_3C_6H_5 \rightarrow C_6H_5SO_3C_6H_4NO_2\text{-}4 \rightarrow 3\text{-}(NO_2)C_6H_4SO_3C_6H_3(NO_2)_2\text{-}2,4$$

$$4\text{-}CH_3C_6H_4SO_3C_6H_5 + 2HNO_3 \rightarrow 3,4\text{-}(NO_2)(CH_3)C_6H_3SO_3C_6H_4NO_2\text{-}4 + 2H_2O$$

The stability of the ester group in aryl sulfonates makes possible a variety of reactions affecting other substituents without hydrolysis or cleavage occurring. Thus the tolyl o- and *p*-toluenesulfonates are oxidized by manganese dioxide and sulfuric acid to the esters of the hydroxyaldehydes and acids,[81] 3-phenanthryl benzenesulfonate is converted to the 9,10-quinone by chromic acid,[82] and 5-nitro-2-methylphenyl benzenesulfonate gives a mixture of the *cis* and *trans* stilbene derivatives when warmed in alkaline solution with sodium hypochlorite.[83] Vanillin has been prepared by the methylation of an ester of 3,4-dihydroxybenzaldehyde[84] followed by hydrolysis, as well as directly by treatment with sodium methoxide in methanol.[85]





Heating *o*-iodophenyl *p*-toluenesulfonate with copper gives the biphenyl derivative in a normal manner.[86] 3-(*p*-Toluenesulfonoxy)-1-naphthamide undergoes the Hoffman reaction without loss of the ester group.[87]

2-Aminophenyl *p*-toluenesulfonate[88] and other similar aminosulfonates[89] show no tendency to isomerize to the anilides, thereby differing from the aminoaryl esters of carboxylic acids. The sulfonates of certain hydroxynitroaldehydes have been converted to the indigo derivatives by treatment with acetone and alkali.[90]

Aside from their value in syntheses aryl sulfonates have been found to have value as moth-proofing agents provided one or both aryl nuclei has one or more halogen atoms attached.[91]

SULFONIC ANHYDRIDES

Sulfonic anhydrides have been little investigated. Benzenesulfonic anhydride was obtained by Billeter[1] as one of the products from the action of silver cyanate upon benzenesulfonyl chloride as well as from heating the chloride with the silver sulfonate[2] at 180°. This and *p*-toluenesulfonic anhydride have been prepared by the action of thionyl chloride upon the acids.[3] In the case of the toluenesulfonic acid the sulfonyl chloride is produced simultaneously.

$$C_6H_5SO_2Cl + C_6H_5SO_3Ag \rightarrow (C_6H_5SO_2)_2O + AgCl$$

$$2C_6H_5SO_3H + SOCl_2 \rightarrow (C_6H_5SO_2)_2O + 2HCl + SO_2$$

Benzenesulfonic anhydride melts at 92° and distils with decomposition at 240° (10 mm.). *p*-Toluenesulfonic anhydride melts at 125°. The anhydrides are little affected by standing with cold water although they hydrolyze upon heating.[2] With alcohol the acid and ester result[2] and with ammonia the ammonium sulfonate and sulfonamide are formed.[3]

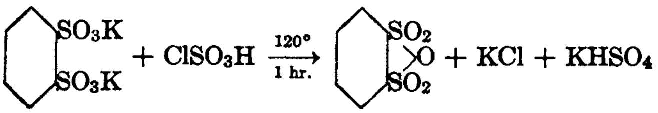
$$(C_6H_5SO_2)_2O + C_2H_5OH \rightarrow C_6H_5SO_3C_2H_5 + C_6H_5SO_3H$$

$$(C_6H_5SO_2)_2O + 2NH_3 \rightarrow C_6H_5SO_2NH_2 + C_6H_5SO_3NH_4$$

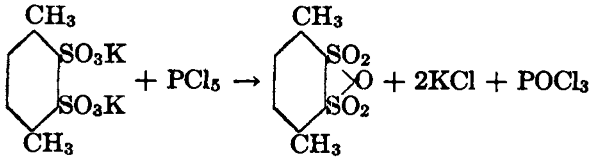
By heating benzenesulfonic anhydride to 160–170° with thionyl chloride under pressure chlorobenzene results.[3]

$$(C_6H_5SO_2)_2O + SOCl_2 \rightarrow 2C_6H_5Cl\ (+\ 3SO_2)$$

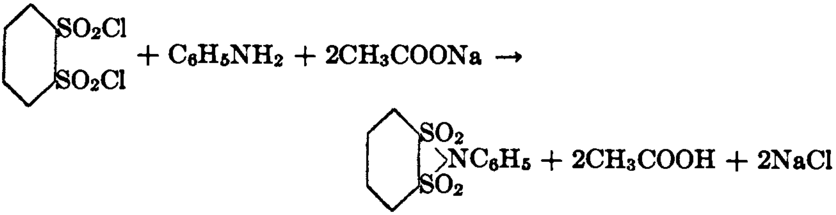
Benzene-*o*-disulfonic anhydride has been prepared by the action of chlorosulfonic acid upon the potassium salt of the acid,[4] and *p*-xylene-



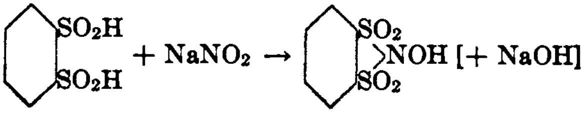
2,3-disulfonic anhydride results from the action of phosphorus pentachloride upon the acid.[5] These anhydrides are high-melting solids



(180 and 189° respectively), but their properties remain otherwise little investigated. The imide corresponding to benzene-*o*-disulfonic anhydride is described under saccharin. The phenylimide has been prepared from the disulfonyl chloride.[8]



The N-hydroxyimide has also been made.[8]

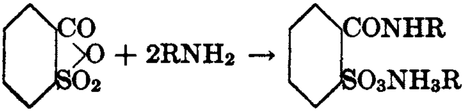


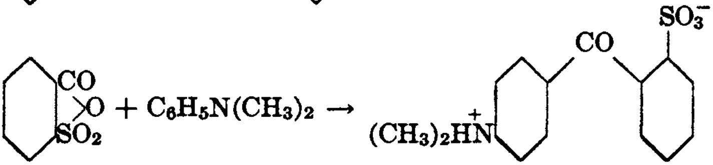
MIXED SULFONIC-CARBOXYLIC ANHYDRIDES

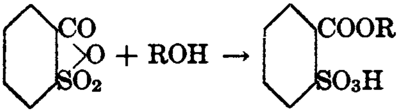
When sulfonyl chlorides are heated with silver acetate an exothermic reaction starts at about 120° which produces the mixed anhydride[6] in yields ranging up to 40%. If sodium acetate is substituted for the silver salt prolonged heating at 200° is necessary to obtain the anhydrides, and the yields are very low. Aliphatic sulfonyl chlorides give higher yields than do the aromatic compounds. Acetic benzenesulfonic anhydride distils at 160–161° (20 mm.) and the *p*-toluenesulfonic compound at 186–188° (20 mm.).

The only mixed anhydride that has received intensive study is that derived from *o*-sulfobenzoic acid. This acid and its salts are easily obtained by the hydrolysis of saccharin, and the anhydride has been much utilized in preparing sulfonephthaleins. The action of phosphorus pentachloride,[7] preferably at room temperature,[8] on dipotassium *o*-sulfobenzoate, of acetyl chloride upon the free acid,[9] and of thionyl chloride upon an acid salt [10] have proved satisfactory as methods for preparing the anhydride. Of these the action of thionyl chloride upon ammonium *o*-carboxybenzenesulfonate is most convenient. The anhydride is also produced by heating the free acid, alone or with phosphorus pentoxide.[10a]

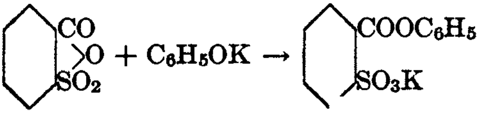
Reaction of *o*-sulfobenzoic anhydride with any reagent which opens the anhydride ring yields a sulfonic acid or its salt. Thus with ammonia,[8] amines,[11] and alcohols [11b] the reactions are as shown in the equations.



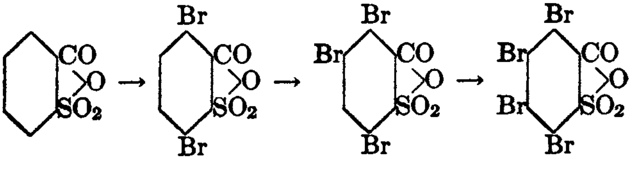




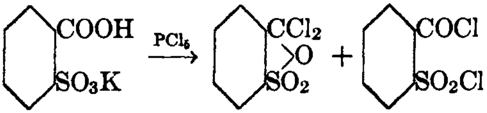
Reaction with a phenol in aqueous alkali [12] likewise yields the ester. (For the reaction under anhydrous conditions see the next section.)

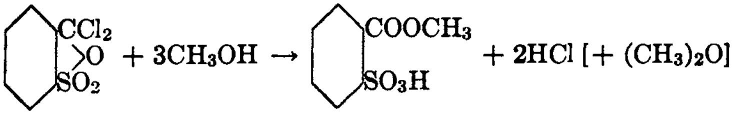


Halogenation of *o*-sulfobenzoic anhydride in 40% oleum leads finally to complete replacement of the hydrogens.[13] Two of the intermediates have been isolated.

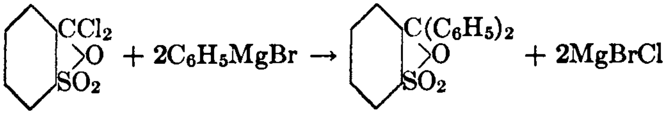


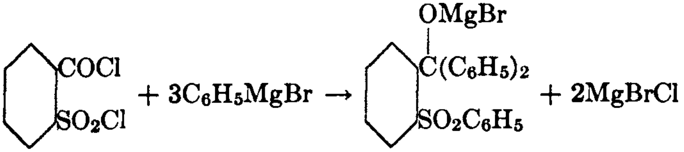
Since the action of phosphorus pentachloride upon salts of *o*-sulfobenzoic acid gives two dichlorides, the "stable" and "unstable" forms,[11,14] one of these is obviously a derivative of the anhydride. Both chlorides with alcohol yield the mono ester. If the alcohol is anhydrous one would expect an ether as the by-product.





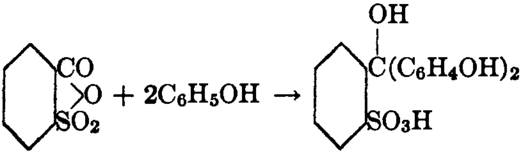
The action of phenylmagnesium bromide upon the low-melting dichloride yields a lactone while the high-melting isomer is converted into a sulfone.[15] These results are best explained by the accompanying equations although they do not constitute a proof of the structures





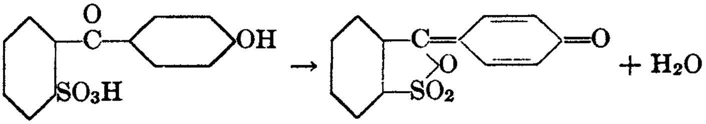
of the dichlorides. The lactone has also been obtained by several investigators [16] by the action of the dichlorides upon benzene in the presence of aluminum chloride. The success of this reaction is apparently determined by unknown factors, since Remsen and Saunders [16a] were not able to repeat their preparation and Cobb [15a] also did not isolate the lactone. The supposed lactone reported by Sachs [17] which resulted from treating triphenylcarbinol-*o*-sulfonmethylamide with hydrochloric or sulfuric acid is actually a saccharin derivative.[16b]

Preparation of Sulfonephthaleins. By far the greater part of the interest in *o*-sulfobenzoic anhydride arises from its condensation with phenolic compounds to yield sulfonephthaleins. Heating with phenol [7,18] at 130–135° for 6 hours brings about condensation without

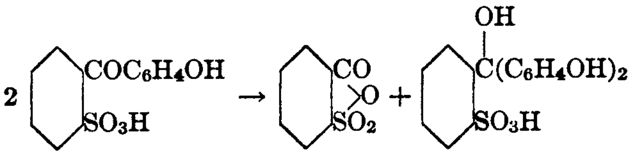


a catalyst being necessary. Either the anhydride or a mixture of the isomeric acid chlorides already mentioned may be utilized in this reaction.[16a,e;18] A by-product of the reaction is *p*-(*o*-sulfobenzoyl)-

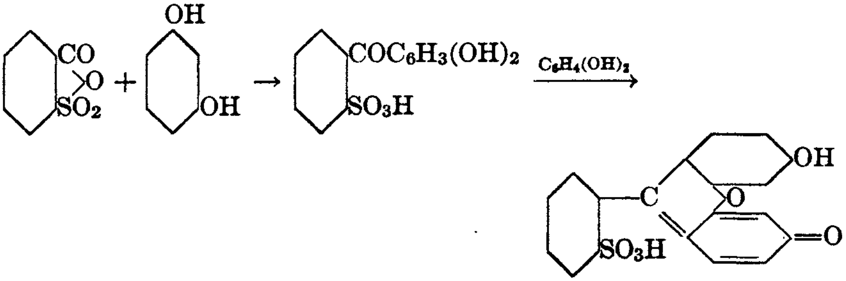
phenol which readily loses water to yield a colored substance probably having the structure shown.

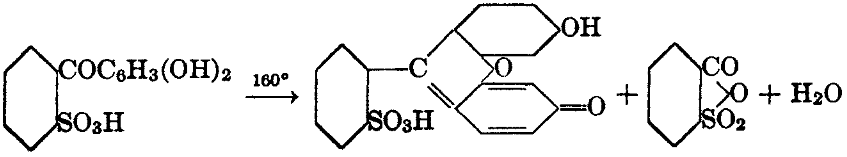


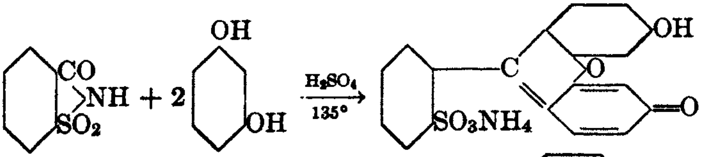
Upon heating to 135–140° disproportionation occurs with formation of phenolsulfonephthalein.

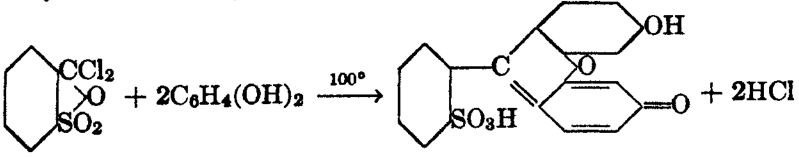


The condensation of *o*-sulfobenzoic anhydride with substituted phenols[19] and more particularly with resorcinol[7,20] has been much studied. Apparently sulfonefluorescein had not been obtained in a pure state, however, until comparatively recently.[21] In this investigation it was prepared by the methods indicated by the equations.





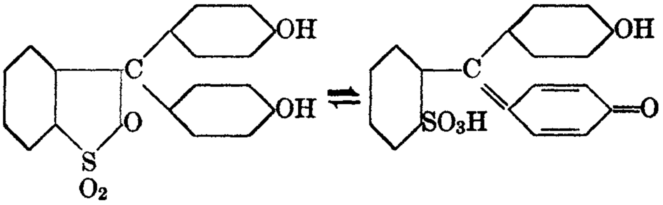




In the last reaction a mixture of the isomeric dichlorides was utilized.

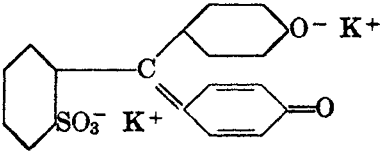
The ring halogenated derivatives of *o*-sulfobenzoic anhydride have also been converted into compounds of the sulfonephthalein type.[22]

Uses of Sulfonephthaleins. Unlike phenolphthalein, the sulfonephthaleins exist chiefly as the free acids [23] rather than the lactones and these acids are predominantly in the quinone form.

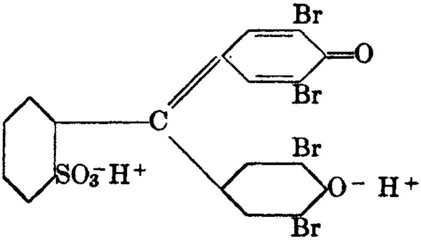


I II

The free acid and its salts are yellow, a red color developing only when enough alkali is added to the solution to produce the salt of the phenolic group as in III.



III



IV

The tetrabromo compound IV is also highly colored as here the bromines enhance the ionization of the phenolic hydrogen.[24] This is also true of the corresponding tetranitro compound, but here the nitro groups may have an effect on the color other than that arising from increased ionization of the phenol. The solutions of both compounds become yellow when hydrochloric acid is added. These observations and those on substituted phenolsulfonephthaleins have interesting implications for the theory of indicators which cannot be discussed here.[25]

The phenolsulfonephthaleins have proved to be exceptionally useful as indicators, and the literature which deals with their use is voluminous.[26] Phenolsulfonephthalein (phenol red) has also proved to be remarkably interesting physiologically. It is excreted by the kidneys and a retardation of excretion is a sensitive indication of kidney disability.[27] A detailed consideration of the voluminous literature on this and related subjects is outside the scope of the present discussion.

REFERENCES

SULFONYL HALIDES

1. Steinkopf, Buchheim, Beythien, Dudek, Eisold, Gall, Jaeger, Reumeth, Semenoff, and Wemme, *J. prakt. Chem.*, [2] **117**, 1–82 (1927); Steinkopf, German pat., **497,242**, *C.A.*, **24**, 3516 (1930).
2. Steinkopf and Jaeger, *J. prakt. Chem.*, [2] **128**, 65 (1930).
3. Steinkopf and Hübner, *ibid.*, [2] **141**, 193 (1934).

4*a*. Davies and Dick, *J. Chem. Soc.*, 2104 (1931). *b*. Davies and Dick, *ibid.*, 2042 (1932).

5. Bennett and Youle, *ibid.*, 887 (1938).
6. Gibson, *J. prakt. Chem.*, [2] **142**, 218 (1935); Gibson and Cowie, *J. Chem. Soc.*, 47 (1934).
7. Gebauer-Fülnegg and Riesz, Austrian pat., 119,960, *C.A.*, **25**, 1262 (1931); Pollak, Gebauer-Fülnegg, and Riesz, *Monatsh.*, **46**, 383 (1926); Pollak, Gebauer-Fülnegg, and Blumenstock, *ibid.*, **46**, 499 (1926); Pollak and Gebauer-Fülnegg, *ibid.*, **47**, 109 (1926); Pollak, Gebauer-Fülnegg, Weinmayr, and Litvay, *ibid.*, **47**, 537 (1927); Pollak, Gebauer-Fülnegg, and Blumenstock-Halward, *ibid.*, **49**, 187 (1928); Pollak, Blumenstock-Halward, Schlesinger, Weinmayr, and Winter, *ibid.*, **49**, 203 (1928); Litvay, Riesz, and Landau, *Ber.*, **62B**, 1863 (1929); Pollak, Gebauer-Fülnegg, and Blumenstock-Halward, *Monatsh.*, **53–54**, 83 (1929).
8. I. G. Farbenind. A.-G., French pat., **690,112**, *C.A.*, **25**, 973 (1931); Schweitzer and Burr, German pat., 516,678, *C.A.*, **25**, 2737 (1931); German pat., 532,399, *C.A.*, **26**, 3262 (1932); Lustig and Katscher, *Monatsh.*, **48**, 87 (1927).
9. Gebauer-Fülnegg and Schlesinger, *Ber.*, **61B**, 781 (1928).
10. Gebauer-Fülnegg and Meissner, *Monatsh.*, **50**, 55 (1928).

11*a*. Suter, *J. Am. Chem. Soc.*, **53**, 1112 (1931). *b*. Huntress and Carten, *ibid.*, **62**, 603 (1940).

12*a*. Stewart, *J. Chem. Soc.*, **121**, **2555** (1922). *b*. Gauntlett and Smiles, *ibid.*, **127**, **2745** (1925).

13. Brown and Robinson, *ibid.*, **111**, 952 (1917).
14. Johnson and Smiles, *ibid.*, **123**, **2384** (1923).
15. For complete references to the action of chlorosulfonic acid on various compounds the section on sulfonation reactions should be consulted.

16*a*. Heumann and Köchlin, *Ber.*, **15**, 1118 (1882). *b*. Zincke and Kempf, *Ber.*, **44**, 418 (1911). *c*. Fabr. de Thann et Mulhouse, German pat., **142,116**, *Chem. Zentr.*, II, 79 (1903). *d*. Green, Marsden, and Scholefield, *J. Chem. Soc.*, **85**, 1432 (1904). *e*. Höchster Farbw., German pat., **266,521**, *Chem. Zentr.*, II, 1716 (1913); Goldyrev and Postovskiy, *J. Applied Chem. (U.S.S.R.)*, **11**, 316 (1938); *C.A.*, **32**, 5800 (1938).

17. Anschütz, *Ann.*, **358**, 94 (1908).
18. Kekulé and Barbaglia, *Ber.*, **5**, 876 (1872); Kekulé, *Ber.*, **6**, 943 (1873).
19. Anschütz and Molineus, *Ann.*, **415**, 53 (1918).

20. Anschütz, *Ann.*, **415**, 64 (1918).
21. v. Szathmáry, *Ber.*, **43**, 2486 (1910).
22. Pollak, v. Fiedler, and Roth, *Monatsh.*, **39**, 193 (1918).
23. Pollak and Wienerberger, *ibid.*, **35**, 1471 (1914).
24*a*. Anschütz and Cürten, *Ann.*, **457**, 256 (1927). *b*. Zincke and Brune, *Ber.*, **44**, 187 (1911).
25. Deutsch-Koloniale Gerb. and Farbstoff-Ges., m.b.H., German pat., 293,042, *C.A.*, **11**, 1520 (1917); German pat., 293,693, *C.A.*, **11**, 2581 (1917).
26. Zincke and Ebel, *Ber.*, **47**, 926, 1103 (1914); Zincke and Arnold, *Ber.*, **50**, 119 (1917); Zincke and Ruppersberg, *Ber.*, 48, 123 (1915); Rennert, *Ber.*, **48**, 462 (1915); Zincke and Deriser, *Ber.*, **51**, 354 (1918).
27. I. G. Farbenind. A.-G., British pat., 397,190, *C.A.*, **28**, 783 (1934).
28*a*. Otto, *Ann.*, **145**, 323 (1868). *b*. Ohse, German pat., 550,685, *C.A.*, **26**, 4828 (1932); Douglass and Johnson, *J. Am. Chem. Soc.*, **60**, 1486 (1938). *c*. Schiller and Otto, *Ber.*, **9**, 1637 (1876). *d*. Johnson and Douglass, *J. Am. Chem. Soc.*, **61**, 2548 (1939).
29. Limpricht, *Ann.*, **278**, 246 (1894).
30*a*. Zincke, *Ann.*, **400**, 10 (1913). *b*. Sprague and Johnson, *J. Am. Chem. Soc.*, **59**, 2439 (1937).
31. Ullmann and Lehner, *Ber.*, **38**, 732 (1905); Basler, Chem. Fabr., German pat., 124,407, *Chem. Zentr.*, II, 961 (1901).
32. Otto and v. Gruber, *Ann.*, **142**, 98, 101 (1867).
33. Zincke and Frohneberg, *Ber.*, **43**, 840 (1910).
34. Zincke and Röse, *Ann.*, **406**, 134 (1914).
35. Zincke and Frohneberg, *Ber.*, **42**, 2728 (1909).
36. Zincke and Krüger, *Ber.*, **45**, 3472 (1912).
37. Tröger and Meine, *J. prakt. Chem.*, [2] **68**, 317 (1903).
38. Reference 37, p. 334.
39. Zincke and Dahm, *Ber.*, **45**, 3461 (1912).
40. Pollak and Tucaković, *Monatsh.*, **31**, 699 (1910).
41*a*. Fries and Vogt, *Ann.*, **381**, 337 (1911). *b*. Bbunetti, *J. prakt. Chem.*, [2] **128**, 44 (1930). *c*. Davies, Storrie, and Tucker, *J. Chem. Soc.*, 624 (1931).
42. Otto and Ostrop, *Ann.*, **141**, 96 (1867).
43. Otto, *Ann.*, **136**, 154 (1865).
44. Otto, *J. prakt. Chem.*, [2] **30**, 179 (1884).
45. Zincke and Jörg, *Ber.*, **43**, 3450 (1910); Willgerodt and Klinger, *J. prakt. Chem.*, [2] **85**, 190 (1912).
46. Otto and Tröger, *Ber.*, **24**, 1138 (1891).
47. Otto and Rössing, *Ber.*, **24**, 3881 (1891).
48. Otto and Tröger, *Ber.*, **24**, 494 (1891).
49. Chattaway, *J. Chem. Soc.*, **87**, 149 (1905).
50. Marckwald and v. Droste-Hülshoff, German pat., 105,370, *Chem. Zentr.*, I, 524 (1900).
51. Limpricht and Hansen, *Ber.*, 18, 2174 (1885).
52. Johnson and McCollum, *Am. Chem. J.*, **35**, 66 (1906).
53*a*. Töhl and Eberhard, *Ber.*, **26**, 2941 (1893); Böeseken, *Rec. trav. chim.*, **30**, 382 (1911). *b*. Meerwein, Büchner, and Emsteb, *J. prakt. Chem.*, [2] **152**, 237 (1939).
54. I. G. Farbenind. A.-G., French pat., 739,290, *C.A.*, **27**, 1894 (1933); British pat., 384,722, *C.A.*, **27**, 4251 (1933); German pat., 574,836, *C.A.*, **27**, 4543 (1933).

55. Martin and Partington, *J. Chem. Soc.*, 1182 (1936).

56. Timmermans, *Bull. soc. chim. Belg.*, **44**, 17 (1935).

57*a*. Freiman and Sugden, *J. Chem. Soc.*, 263 (1928). *b*. Harding, *ibid.*, **119**, 260 (1921).

58. Ullmann and Kertész, *Ber.*, **52B**, 545 (1919).

59. Claësson and Wallin, *Ber.*, **12**, 1849 (1879); Wolkowa, *J. Russ. Phys.-Chem. Soc.*, **2**, 165 (1870); Kimberly, *Ann.*, **114**, 131 (1860).

60*a*. Olivier, *Rec. trav. chim.*, **33**, 101 (1914). *b*. Heinzelmann, *Ann.*, **188**, 160 (1877). *c*. Claësson, *Ber.*, **14**, 307 (1881). *d*. Widmann, *Ber.*, **12**, 2229 (1879). *e*. Cleve, *Ber.*, **23**, 962 (1890). *f*. Arnell, *Ber.*, **17R**, 48 (1884).

61. Lampe, *Ber.*, **42**, 1417 (1909).

62*a*. Otto, *Ann.*, **147**, 185 (1868). *b*. Wilson, Fuller, and Schur, *J. Am. Chem. Soc.*, **44**, 2762 (1922).

63*a*. Nölting, *Ber.*, **8**, 597 (1875). *b*. Fahlberg, *Ber.*, **12**, 1052 (1879). *c*. Fahlberg and List, German pat., 35,211, *Frdl.*, **1**, 592. *d*. Armstrong and Wynne, *Chem. News*, **61**, 273 (1890); **76**, 69 (1897); Cleve, *Chem.-Ztg.*, **17**, 398 (1893).

64. Beckmann, *Ber.*, **38**, 904 (1905).

65. Schiller and Otto, *Ber.*, **9**, 1585 (1876); Otto, *Ber.*, **10**, 940 (1877); **26**, 2051 (1893).

66*a*. Ullmann and Pasdermadjian, *Ber.*, **34**, 1151 (1901). *b*. Tröger and Voigtlander-Tetzner, *J. prakt. Chem.*, [2] **54**, 513 (1896). *c*. Bourgeois, *Rec. trav. chim.*, **18**, 437 (1899). *d*. Pauly, *Ber.*, **9**, 1595 (1876). *e*. Whitmore and Hamilton, *Org. Syntheses, Coll. Vol. I*, John Wiley & Sons, 1932, p. 479.

67. Otto, Rossing, and Tröger, *J. prakt. Chem.*, [2] **47**, 94 (1893); Heffter, *Ber.*, **28**, 2258 (1895); Tröger and Meine, *J. prakt. Chem.*, [2] **68**, 315, 330 (1903).

68*a*. Perl, *Ber.*, **18**, 67 (1885). *b*. Pearl, Evans, and Dehn, *J. Am. Chem. Soc.*, **60**, 2478 (1938).

69. Otto, *Ber.*, **26**, 2051 (1883); *Ann.*, **143**, 208 (1867); **147**, 185 (1868); Otto and Ostrop, *Ann.*, **141**, 366 (1867); Otto and v. Gruber, *Ann.*, **142**, 93 (1867); Gessner, *Ber.*, **9**, 1500 (1876); Gabriel and Deutsch, *Ber.*, **13**, 390 (1880).

70. Otto and v. Gruber, *Ann.*, **145**, 23 (1868).

71. Kalle, *Ann.*, **119**, 161 (1861).

72. Vogt, *Ann.*, **119**, 142 (1861); Bourgeois, *Ber.*, **28**, 2319 (1895); *Rec. trav. chim.*, **18**, 433 (1899); Ottto, *Ber.*, **10**, 939 (1877); Adams and Marvel, *Org. Syntheses, Coll. Vol. I*, John Wiley & Sons, New York, 1932, p. 490; Otto, *Ann.*, **143**, 106 (1867); Märcker, *Ann.*, **136**, 79, 88 (1865); Schertel, *Ann.*, **132**, 91 (1864); Maïkopar, *Z. Chem.*, 711 (1869); Billeter, *Ber.*, **8**, 463 (1875).

73. Pollak, Pollak, Riesz, and Wittels, *Monatsh.*, **58**, 118 (1931).

74*a*. Friedländer and Mauthner, *Chem. Zentr.*, II, 1176 (1904). *b*. Hübner and Miller, *Ann.*, **169**, 50 (1873). *c*. Klason and Carlson, *Ber.*, **39**, 739 (1906). *d*. Pazschke, *J. prakt. Chem.*, [2] **2**, 418 (1870). *e*. Korner and Monselise, *Gazz. chim. ital.*, **6**, 140 (1876). *f*. Gabriel and Deutsch, *Ber.*, **13**, 390 (1880). *g*. Pollak and Carniol, *Ber.*, **42**, 3252 (1909). *h*. Flurschiem, *J. prakt. Chem.*, [2] **71**, 518, 526 (1905).

75*a*. Hess, *Ber.*, **14**, 489 (1881). *b*. Glutz and Schrank, *J. prakt. Chem.*, [2] **2**, 223 (1870). *c*. Scrutchfield, Ph.D. thesis, Northwestern University, 1935. *d*. Decker and Fellenberg, *Ann.*, **356**, 326 (1907).

76. Karrer, Wehrli, Biedermann, and Vedova, *Helv. Chim. Acta*, **11**, **233** (1928).

77. Fichter and Bernoulli, *Z. Elektrochem.*, **13**, 310 (1907); Fichter and Tamm, *Ber.*, **43**, 3032 (1910).

78. Fichter and Bernoulli, *Ber.*, **42**, 4309 (1909).

79. Smet, *Natuurw. Tijdschrift*, **15**, 215 (1933); *C.A.*, **28**, 3063 (1934).

80. Ekbom, *Ber.*, **24**, 335 (1891).

81*a*. Cleve, *Ber.*, **21**, 1100 (1888); **20**, 1534 (1887); **23**, 959 (1890). *b*: Miescher and Billeter, *Helv. Chim. Acta*, **22**, 601 (1939).

82. Ekbom, *Ber.*, **35**, 653 (1902).

83. Langmuir, *Ber.*, **28**, 96 (1895).

84. Gebauer-Fülnegg, Riesz, and Ilse, *Monatsh.*, **49**, 41 (1928); Perret and Perrot, *Bull. soc. chim.*, [5] **1**, 1531 (1934).

85. Otto, *J. prakt. Chem.*, [2] 37, 213 (1888).

86. Otto, *ibid.*, [2] **49**, 380 (1894).

87. Höchster Farbw., German pat., 224,019, *Chem. Zentr.*, II, 513 (1910); Fromm and Erfurt, *Ber.*, **42**, 3821 (1909).

88. Spring, *Ber.*, **7**, 1158 (1874); Otto, *Ber.*, **15**, 127 (1882); Tröger and Linde, *Arch. Pharm.*, **239**, 124 (1901); Tröger and Hurdelbrink, *J. prakt. Chem.*, [2] **65**, 89 (1902); Tröger and Grothe, *ibid.*, [2] **56**, 473 (1897); Blomstrand, *Ber.*, **3**, 963 (1870); Gutman, *Z. anal. Chem.*, **47**, 297 (1905); Tröger and Meine, *Ber.*, **35**, 2164 (1902); *J. prakt. Chem.*, [2] **68**, 329 (1903).

89. Limpricht, *Ann.*, **278**, 240 (1894).

90. Blomstrand, *Ber.*, 3, 965 (1870); Limpricht, *Ber.*, **25**, 75, 3477 (1892); Bere and Smiles, *J. Chem. Soc.*, **125**, 2361 (1924).

91. Gutmann, *Ber.*, **42**, 481 (1909).

92. Wallach, *Ann.*, **214**, 219 (1882).

93*a*. Graebe and Kraft, *Ber.*, **39**, 800, 2508 (1906). *b*. Olivier, *Rec. trav. chim.*, **36**, 117 (1916).

94. Weinland and Lewkowitz, *Ber.*, **36**, 2702 (1903).

95. Willstätter and Hauenstein, *Ber.*, **42**, 1848 (1909).

96. Barbaglia and Kekulé, *Ber.*, **5**, 876 (1872); Nölting, *Ber.*, **8**, 1091 (1875); Quilico, *Atti accad. Lincei*, [6] **6**, 512 (1927); *C.A.*, **22**, 1765 (1928).

97. Carius, *Ann.*, **114**, 145 (1860); Armstrong and Wynne, *Chem. News*, **58**, 295 (1888); **59**, 189 (1889); **61**, 93, 274 (1890); **62**, 163 (1890); **71**, 255 (1895); **76**, 69 (1897); Widmann, *Ber.*, **12**, 2229 (1879); Cleve, *Ber.*, **24**, 3478 (1891); **19**, 2181 (1886); *Bull. soc. chim.*, [2] **26**, 245, 540 (1876); *Chem.-Ztg.*, **17**, 398 (1894); Sindall, *Chem. News*, **60**, 58 (1889); Forsling, *Ber.*, **20**, 80 (1887); Sandqvist, *Ann.*, **369**, 113 (1909); Beattie and Whitmore, *J. Am. Chem. Soc.*, **55**, 1546 (1933); Ferrero and Bolliger, *Helv. Chim. Acta*, **11**, 1144 (1928).

98. Meyer, *Monatsh.*, **36**, 719 (1915).

99. Pollak and Rudich, *ibid.*, **43**, 209 (1922).

100. Pollak and Schadler, *ibid.*, **39**, 129 (1918).

101. Hinsberg, *Ber.*, **23**, 2962 (1890); Duden, *Ber.*, **33**, 3526 (1900); *Ann.*, **265**, 178 (1891); Ssolonina, *J. Russ. Phys.-Chem. Soc.*, **29**, 404 (1897); **31**, 640 (1899); Marckwald, *Ber.*, **32**, 3512 (1899); **33**, 765 (1900); Duden, *Ber.*, **33**,

477 (1900); Willstätter and Lessing, *Ber.*, **33**, 557 (1900); Hinsberg and Kessler, *Ber.*, **33**, 906 (1905); Behrens, *Z. anal. Chem.*, **41**, 272 (1902); van Romburgh, *Rec. trav. chim.*, **3**, 16 (1884).

102*a*. Marvel and Smith, *J. Am. Chem. Soc.*, **45**, 2696 (1923). *b*. Marvel, Kingsbury, and Smith, *ibid.*, **47**, 166 (1925). *c*. Ebel, *Ber.*, **60B**, 2079 (1927). *d*. Riesz and Feiks, *Monatsh.*, **52**, 372 (1929). *e*. Schwartz and Dehn, *J. Am. Chem. Soc.*, **39**, 2444 (1917).

103. Jones and Whaley, *ibid.*, **47**, 1343 (1925); references to previous partially erroneous reports are given by these authors.

104. Bergel and Döring, *Ber.*, **61B**, 844 (1928); Wahl, *Rev. gén. mat. color.*, **32**, 176 (1928); *C.A.*, **23**, 1896 (1929); Gebauer-Fülnegg and Schwarz, *Ber.*, **61B**, 1307 (1928).

105. Michler and Meyer, *Ber.*, **12**, 1793 (1879).

106. Schwartz and Dehn, *J. Am. Chem. Soc.*, **39**, 2444 (1917).

107. Slotta and Behnisch, *Ann.*, **497**, 170 (1932).

108. Curtius and Lorenzen, *J. prakt. Chem.*, [2] **58**, 166 (1898); Kahl, *Chem. Zentr.*, II, 1494 (1904); Hinsberg, *Ber.*, **27**, 601 (1894).

109. Dann and Davies, *J. Chem. Soc.*, 1050 (1929).

110. Davies, Storrie, and Tucker, *ibid.*, 624 (1931).

111. Witte, *Rec. trav. chim.*, **51**, 299 (1932).

112. Bailey and Acree, *Ber.*, **33**, 1521 (1900); v. Rothenburg, *Ber.*, **27**, 689 (1894); Fischer and Hunsalz, *Ber.*, **27**, 183 (1894); Thiele, *Ann.*, **376**, 249 (1910).

113. Claasz, *Ber.*, **44**, 1417 (1911).

114. Piloty, *Ber.*, **29**, 1560 (1896); Angeli, Angelico, and Scurti, *Gazz. chim. ital.*, **33**, II, 311 (1903); *Atti. accad. Lincei*, [5] **11**, I, 557 (1902).

115. Hantzsch and Sauer, *Ann.*, **299**, 81 (1898).

116. Wege, *Ber.*, **24**, 3538 (1891).

117. Forster and Fierz, *J. Chem. Soc.*, **93**, 678 (1908); Börnstein, *Ber.*, **29**, 1484 (1896); Bridge, *Ann.*, **277**, 83 (1893).

118. Werner and Piguet, *Ber.*, **37**, 4295 (1904).

119. Forster and Judd, *J. Chem. Soc.*, **97**, 263 (1910).

120. Arndt and Scholz, *Ber.*, **66B**, 1012 (1933).

121. Pinnow, *Ber.*, **26**, 606 (1893).

122. Pinnow, *Ber.*, **24**, 4174 (1891).

123. Tieman, *Ber.*, **24**, 4164 (1891); Pinnow, *Ber.*, **24**, 4171 (1891).

124. Werner and Buss, *Ber.*, **28**, 1281 (1895).

125. Werner and Subak, *Ber.*, **29**, 1156 (1896).

126. Ackermann, *Z. physiol. Chem.*, **47**, 366 (1906).

127. Hebenstreit, *J. prakt. Chem.*, [2] **41**, 99 (1890).

128. Billeter, *Ber.*, **38**, 2018 (1905).

129. Fromm and Heyder, *Ber.*, **42**, 3804 (1909).

130. Remsen and Turner, *Am. Chem. J.*, **25**, 190 (1901).

131. Chem. Fabr. von Heyden, German pat., 123,052, *Frdl.*, **6**, 35.

132. Ullmann and Nádai, *Ber.*, **41**, 1871 (1908).

133. Billeter, *Ber.*, **38**, 2018 (1905); Abrahall, *J. Chem. Soc.*, 49, 692 (1886); Hübner, *Ann.*, **223**, 244 (1884).

134. Gerhardt, "Traité de chimie organique," Vol. III, Paris, 1854, p. 75.

135. Höchster Farbw., German pat., 125,390, *Chem. Zentr.*, II, 1185 (1901).

136. Kohler and MacDonald, *Am. Chem. J.*, **22**, 232 (1899); v. Meyer and Findeisen, *J. prakt. Chem.*, [2] **65**, 529 (1902).

137*a*. Private communication, Hauser and Hudson, Duke University. *b*. Jackson and Whitmore, *J. Am. Chem. Soc.*, **37**, 1926 (1915).

138*a*. Bourguel and Truchet, *Compt. rend.*, **190**, 753 (1930). *b*. Truchet, *Ann. chim.*, **16**, 309 (1931).

139*a*. Hepworth and Clapham, *J. Chem. Soc.*, **119**, 1188 (1921). *b*. Wedekind and Schenk, *Ber.*, **54B**, 1604 (1921). *c*. Gilman and Fothergill, *J. Am. Chem. Soc.*, **51**, 3501 (1929); Le Fevre and Markham, *J. Chem. Soc.*, 703 (1934). *d*. Truchet, *Compt. rend.*, **191**, 296 (1930).

140. Kalle, *Ann.*, **119**, 155 (1861).

141. Blaise, *Bull. soc. chim.*, [4] **9**, 1 (1911).

142. Otto, *Ber.*, **18**, 249 (1885).

143. Krafft and Roos, *Ber.*, **25**, 2257 (1892); Finzi, *Ann. chim. applicata*, **15**, 41 (1925); Goubau, *Chem. Zentr.*, II, 18 (1911).

144. Krafft and Roos, *Ber.*, **26**, 2826 (1893).

145. Ullmann and Wenner, *Ann.*, **327**, 121 (1903); Flurscheim, *J. prakt. Chem.*, [2] **71**, 525 (1905).

146. Gilman and Beaber, *J. Am. Chem. Soc.*, **47**, 522 (1925).

147. Slotta and Franke, *Ber.*, **63B**, 678 (1930).

148. Clemo and Perkin, *J. Chem. Soc.*, **121**, 642 (1922); Gilman and Beaber, *J. Am. Chem. Soc.*, **45**, 839 (1923).

149. Clemo and Walton, *J. Chem. Soc.*, 723 (1928).

150*a*. Földi, *Ber.*, **53**, 1836 (1920). *b*. Izmail'skii and Razorenov, *J. Russ. Phys.-Chem. Soc.*, **52**, 359 (1920); *C.A.*, **18**, 1481 (1924). *c*. Rossander and Marvel, *J. Am. Chem. Soc.*, **50**, 1491 (1928). *d*. Boyle, *J. Chem. Soc.*, **95**, 1704 (1909). *e*. Demény, *Rec. trav. chim.*, **50**, 60 (1931).

151. Hahn and Walter, *Ber.*, **54B**, 1531 (1921).

152. Hübner, *Ann.*, **223**, 237 (1884).

153. Ferns and Lapworth, *J. Chem. Soc.*, **101**, 276 (1912).

154. Vorländer and Nolte, *Ber.*, **46**, 3219 (1913).

155. Patterson and Frew, *J. Chem. Soc.*, **89**, 333 (1906); Hilditch, *ibid.*, **99**, 238 (1911); Slotta and Lorenz, *Ber.*, **58B**, 1320 (1925); Sekera and Marvel, *J. Am. Chem. Soc.*, **55**, 345 (1933); Tabern and Volwiler, *ibid.*, **56**, 1141 (1934); Phillips, *J. Chem. Soc.*, **123**, 44 (1923).

156. The term "tosyl" is in general use among carbohydrate chemists as an abbreviation for "*p*-toluenesulfonyl"; Hess and Stenzel, *Ber.*, **68B**, 981 (1935); Ohle and Thiel, *Ber.*, **66B**, 525 (1933) and many preceding papers in the same series; Reynolds, *J. Chem. Soc.*, **2626** (1931); Müller, *Ber.*, **65B**, 1055 (1932); Bodycote, Haworth, and Hirst, *J. Chem. Soc.*, 151 (1934); Muskat, *J. Am. Chem. Soc.*, **56**, 2655 (1934); Vargha, *Ber.*, **68B**, 1377 (1935); many other "tosylations" have been carried out but it is believed that those included in the references are typical.

157. Herzog, *Monatschr. Textil-Ind.*, **45**, 480 (1930); *C.A.*, **26**, 3925 (1932).

158. Reverdin and Crépieux, *Bull. soc. chim.*, [3] **25**, 1047 (1901); *Ber.*, **34**, 2999 (1901).

159. Schiaparelli, *Gazz. chim. ital.*, **11**, 66 (1881).

160. Georgescu, *Ber.*, **24**, 416 (1891); Wohlleben, *Ber.*, **42**, 4375 (1909); Gilliard, Monnet, and Cartier, German pat., 91,314, *Frdl.*, **4**, 41; Badische Anilin- und Sodafabrik, German pat., 162,322, *Chem. Zentr.*, II, 726 (1905); Kastle and Speyer, *Am. Chem. J.*, **27**, 40 (1902); Otto, *J. prakt. Chem.*, [2] **47**, 374 (1893); Ullmann and Brittner, *Ber.*, **42**, 2546 (1909); A.-G.

für Anilinfabr., German pat., 185,547, *Chem. Zentr.*, II, 863 (1907); Chem. Fabrik Schering, German pat., 76,493, *Frdl.*, **4**, 136; Rupp and Linck, *Arch. Pharm*, **253**, 38 (1915); Hinsberg, *Ber.*, **48**, 2094 (1915).

161*a*. Ullmann and Lowenthal, *Ann.*, **332**, 63 (1904). *b*. Ullmann, German pat., 194,951, *Chem. Zentr.*, I, 1115 (1908). *c*. Borsche, *Ber.*, **50**, 1347 (1917). *d*. Friedländer and Schenck, *Ber.*, **47**, 3045 (1914). *e*. Sané and Joshi, *J. Chem. Soc.*, **125**, 2481 (1924).

162. Bamberger and Rising, *Ber.*, **34**, 241 (1901); Baudisch, Pistor, and Silberblatt, *Ber.*, **49**, 193 (1916); A.-G. für Anilinfabrik, German pat., 240,038, *Chem. Zentr.*, II, 1565 (1911).

163. Fichter and Walter, *Ber.*, **42**, 4311 (1909).

164*a*. Otto, *Ber.*, **19**, 1832 (1886). *b*. Neunhoeffer and Kölbel, *Ber.*, **68B**, 255 (1935). *c*. Amundsen and Pollard, *J. Am. Chem. Soc.*, **57**, 1535 (1935). *d*. Borsche and Scholten, *Ber.*, **50**, 602 (1917).

165*a*. Ullmann and Nádai, *Ber.*, **41**, 1870 (1908). *b*. Ullmann and Bruck, *Ber.*, **41**, 3933 (1908); Borsche and Fiedler, *Ber.*, **46**, 2122 (1913).

166. Reverdin and Crépieux, *Bull. soc. chim.*, [3] **27**, 745 (1902); *Ber.*, **35**, 1443 (1902); Karslake and Huston, *J. Am. Chem. Soc.*, **36**, 1254 (1914); Huston, *ibid.*, **37**, 2120 (1915); Sekera and Marvel, *ibid.*, **55**, 345 (1933); Sekera, *ibid.*, **55**, 421 (1933); Bell and Kenyon, *J. Chem. Soc.*, 3044 (1926); Bell and Robinson, *ibid.*, 1127 (1927).

167. Slotta and Behnisch, *J. prakt. Chem.*, [2] **135**, 225 (1932).

168*a*. Ullmann and Sané, *Ber.*, **44**, 3730 (1911). *b*. Sané, Chakravarty, and Parmanick, *J. Indian Chem. Soc.*, **9**, 55 (1932). *c*. Sané and Joshi, *ibid.*, **9**, 59 (1932). *d*. Borsche and Feske, *Ber.*, **61B**, 690 (1928). *e*. Kubota, *J. Chem. Soc. Japan*, **53**, 404 (1932).

169*a*. Joshi, *J. Indian Chem. Soc.*, **10**, 677 (1933). *b*. Bell, *J. Chem. Soc.*, 2343 (1931).

170*a*. Kubota, *J. Chem. Soc. Japan*, **53**, 404 (1932). *b*. Borsche and Feske, *Ber.*, **59B**, 685 (1926).

171*a*. Borsche, Löwenstein, and Quast, *Ber.*, **50**, 1339 (1917). *b*. Borsche and Feske, *Ber.*, **60B**, 157 (1927).

172. Bell, *J. Chem. Soc.*, 613 (1931).

173. Bell, *ibid.*, 2787 (1929); 1072 (1930); 613, 2343 (1931).

174. Otto, *Ber.*, **24**, 714 (1891).

175. Schiller and Otto, *Ber.*, **9**, 1636 (1876).

176. Otto, *Ber.*, **15**, 128 (1882).

177. Blomstrand, *Ber.*, **3**, 963 (1870).

178. Saunders, *Biochem. J.*, **27**, 397 (1933).

179. Ges. für chem. Ind., German pat., 133,000, *Chem. Zentr.*, II, 313 (1902); Geigy & Co., German pat., 210,856, *ibid.*, II, 79 (1909).

180. Davies, *J. Chem. Soc.*, **119**, 853 (1921); McMaster and Carol, *Ind. Eng. Chem.*, **23**, 218 (1931).

181. Davies, *J. Chem. Soc.*, **121**, 785 (1922).

182. Cleve, *Chem.-Ztg.*, **17**, 398, 758 (1893); Arnell, dissertation, Upsala, 1889, p. 18; Erdmann, *Ann.*, **275**, 235 (1893).

183. For a complete survey of this reaction see Chapter VII on sulfones.

184. Olivier, *Chem. Weekblad*, **19**, 260 (1922).

185. Otto and Ostrop, *Ann.*, **141**, 372 (1867); Otto and v. Gruber, *ibid.*, **142**, 98 (1867); Otto, *ibid.*, **145**, 324 (1868); Limpricht, *ibid.*, **278**, 246 (1894);

Ullmann and Lehner, *Ber.*, **38**, 732 (1905); Otto, Rossing, and Tröger, *J. prakt. Chem.*, [2] **47**, 99 (1893); Tröger and Meine, *ibid.*, [2] **68**, 318 (1903).

186*a*. Zincke and Frohneberg, *Ber.*, **42**, 2722 (1909); **43**, 840 (1910). *b*. Kohlhase, *J. Am. Chem. Soc.*, **54**, 2441 (1932).

187*a*. Norton, *ibid.*, **19**, 836 (1897). *b*. Limpricht, *Ann.*, **278**, 246 (1894). *c*. Mauzelius, *Ber.*, **22**, 1844, 2822 (1889). *d*. Arnell, dissertation, Upsala, 1889, p. 16. *e*. Forsling, *Ber.*, **21**, 2803 (1888). *f*. **22**, 619, 1402 (1889). *g*. Sandqvist, *Ann.*, **369**, 114 (1909). *h*. Jolin, *Bull. soc. chim.*, [2] **28**, 516 (1877). *i*. Olivier, *Rec. trav. chim.*, **33**, 120 (1914).

188. Gessner, *Ber.*, **9**, 1504 (1876).

189. Mummery, *Proc. Roy. Society*, **90A**, 455 (1914); Colgate and Rodd, *Chem. News*, **100**, 222 (1909); *J. Chem. Soc.*, **97**, 1591 (1910); Wynne, *ibid.*, **61**, 1041 (1892).

190*a*. Otto and Tröger, *Ber.*, 24, 485 (1891). *b*. Tröger and Hurdelbrink, *J. prakt. Chem.*, [2] 65, 87 (1902). *c*. Otto, Rossing, and Tröger, *ibid.*, [2] **47**, 99 (1893). *d*. Child and Smiles, *J. Chem. Soc.*, 2696 (1926).

191. Whitmore and Thurman, *J. Am. Chem. Soc.*, **45**, 1068 (1923).

ALKYL AND ARYL SULFONATES

1*a*. Hantzsch and Müller, *Ber.*, **62B**, 966 (1929). *b*. Reichstein and Schindler, *Helv. Chim. Acta*, **23**, 669 (1940). *c*. Crossen, Jenkins, and Rogers, *Pharm. Arch.*, **12**, 21 (1941).

2. Simon and Frèrejacque, *Compt. rend.*, **176**, 900 (1923); **177**, 533 (1923); Frèrejacque, *Ann. chim.*, **14**, 147 (1930).

3*a*. Billeter, *Ber.*, **37**, 691 (1904). *b*. Criegee and Stanger, *Ber.*, **69B**, 2753 (1936).

4. Isham, U. S. pat., 1,929,870, *C.A.*, **28**, 174 (1934); see also Brooks and Humphrey, *J. Am. Chem. Soc.*, **40**, 822 (1918).

5. Fairbourne and Foster, *J. Chem. Soc.*, **127**, 2759 (1925).

6. Földi, *Ber.*, **60B**, 656 (1927); **61B**, 1609 (1938).

7*a*. Patterson and McAlpine, *J. Chem. Soc.*, 349 (1927). *b*. *Ibid.*, 2464 (1928).

8. Wegscheider and Furcht, *Monatsh.*, **23**, 1095 (1902).

9*a*. Wegscheider, *Z. physik. Chem.*, **41**, 52 (1902); *Ber.*, **52B**, 235 (1919). *b*. Karlsson, *Z. anorg. allgem. Chem.*, **145**, 1 (1925). *c*. Demeny, *Rec. trav. chim.*, 50, 60 (1931).

10. Praetorius, *Monatsh.*, 26, 13 (1905).

11. Schiller and Otto, *Ber.*, 9, 1639 (1876); Praetorius, *Monatsh.*, **28**, 795 (1907).

12. Autenrieth and Bernheim, *Ber.*, **37**, 3803 (1904).

13. Curtius and Lorenzen, *J. prakt. Chem.*, [2] **58**, 160 (1898).

14. Rodionov, *Bull. soc. chim.*, **45**, 109 (1929).

15. Kastle, Murrill, and Frazer, *Am. Chem. J.*, **19**, 894 (1897).

16*a*. Kimberly, *Ann.*, **114**, 133 (1860). *b*. Földi, *Ber.*, **53B**, 1836 (1920).

17. Földi, *Ber.*, **53B**, 1839 (1920).

18. Kastle and Murrill, *Am. Chem. J.*, **17**, 290 (1895).

19*a*. Sagrebin, *J. Russ. Phys.-Chem. Soc.*, **31**, 19 (1899); *Chem. Zentr.*, I, 1059 (1899). *b*. Rosenfeld-Freiberg, *J. Russ. Phys.-Chem. Soc.*, **34**, 422 (1902); *Chem. Zentr.*, II, 86 (1902). *c*. Kastle, *Am. Chem. J.*, **11**, 177 (1889).

d. Krafft and Roos, *Ber.*, **25**, 2255 (1892); **26**, 2823 (1893); German pat., 69,115, *Frdl.*, **3**, 11. *e.* Praetorius, *Monatsh.*, **28**, 785 (1907).

20*a*. Vernimmen, *Bull. soc. chim. Belg.*, **88**, 96 (1924); Nazarov and Remiz, *C.A.*, **31**, 6187 (1937). *b.* Truchet and Graves, *Bull. soc. chim.*, **51**, 686 (1932). *c.* Ferns and Lapworth, *J. Chem. Soc.*, **101**, 273 (1912). *d.* Kranzfelder and Sowa, *J. Am. Chem. Soc.*, **59**, 1490 (1937).

21*a*. Phillips, *J. Chem. Soc.*, **128**, **44** (1923). *b.* Kenyon, Phillips, and Turley, *ibid.*, **127**, 399 (1925). *c.* Hückel, *Ann.*, **538**, 1 (1937). *d.* Hückel and Tappe, *Ann.*, **537**, 113 (1939). *e.* Hückel, Tappe, and Legutke, *Ann.*, **543**, 191 (1940). *f.* Hückel and Pietrozok, *Ann.*, **543**, 230 (1940).

22*a*. Stoll, *Z. physiol. Chem.*, **246**, 1 (1937). *b.* Gilman and Heck, *J. Am. Chem. Soc.*, **50**, 2229 (1928). *c.* Mine, *J. Chem. Soc. Japan*, **56**, 200, 1112 (1935); *C.A.*, **29**, 7940 (1935); **30**, 441 (1936).

23. Blanchard, *Bull. soc. chim.*, **41**, 824 (1927).

24*a*. Finzi, *Ann. chim. applicata*, **15**, 41 (1925); *C.A.*, **19**, 2647 (1925). *b.* Sekera and Marvel, *J. Am. Chem. Soc.*, **55**, 348 (1933).

25. Slotta and Franke, *Ber.*, **63B**, 678 (1930).

26. Izmail'skii and Razorenov, *J. Russ. Phys.-Chem. Soc.*, **52**, 366 (1920); *C.A.*, **18**, 1481 (1924); Russian pat., 591, *C.A.*, **27**, 5337 (1933); Roncari, *Ing. chim.*, **15**, 1 (1931); *C.A.*, **26**, 2184 (1932).

27*a*. Clemo and Perkin, *J. Chem. Soc.*, **121**, 642 (1922). *b.* Butler, Renfrew, Cretcher, and Souther, *J. Am. Chem. Soc.*, **59**, 227 (1937); Butler, Hostler, and Cretcher, *ibid.*, **59**, 2354 (1937).

28*a*. Clemo and Walton, *J. Chem. Soc.*, 723 (1928). *b.* Gilman and Beaber, *J. Am. Chem. Soc.*, **47**, 1449 (1925).

29*a*. Freudenberg and Hess, *Ann.*, **448**, 121 (1926). *b.* Freudenberg and Huber, *Ber.*, **58B**, 148 (1925). *c.* Földi, *Ber.*, **55B**, 1535 (1922); Marvel, Scott, and Amstutz, *J. Am. Chem. Soc.*, **51**, 3638 (1929).

30. Rodionov and Vvedenskii, *Bull. soc. chim.*, **45**, 121 (1929).

31*a*. Rodionov, *ibid.*, **89**, 305 (1926). *b.* Cary, Vitcha, and Shriner, *J. Org. Chem.*, **1**, 280 (1936).

32. Nikolaiev, *Khim. Farm. Prom.*, No. 1, 35 (1934); *C.A.*, **28**, **5444** (1934).

33. Freudenberg and Hess, *Ann.*, **448**, 121 (1926).

34. Freudenberg, Orthner, and Fikentscher, *Ann.*, **436**, 286 (1924).

35. Peacock and Menon, *Quart. J. Indian Chem. Soc.*, **2**, 240 (1925).

36*a*. Slotta and Lorenz, *Ber.*, **58B**, 1320 (1925). *b.* Müller and Batyka, *Ber.*, **74B**, 705 (1941).

37. Moreu, *Compt. rend.*, **132**, 837 (1901).

38. Wedekind and Schenck, *Ber.*, **54B**, 1604 (1921).

39. Holmberg, *Ber.*, **59B**, 1560 (1926).

40. Rossander and Marvel, *J. Am. Chem. Soc.*, **50**, 1491 (1928).

41. Suter and Gerhart, *ibid.*, **57**, 108 (1935).

42. Jolibois, *Compt. rend.*, **155**, 353 (1912); **188**, 971 (1926).

43. Gilman and Robinson, *Bull. soc. chim.*, **45**, 636 (1929).

44*a*. Gilman and Beaber, *J. Am. Chem. Soc.*, **47**, 523 (1925). *b.* Copenhaver, Roy, and Marvel, *ibid.*, **57**, 1312 (1935). *c.* Gilman and Brown, *Iowa State Coll. J. Sci.*, 6, 11 (1931).

45. Some of the data on yields in the literature were obtained by the use of one mole of sulfonate per mole of Grignard reagent and are therefore much lower than could be produced under optimum conditions. Excep-

tions are the procedure for the preparation of *n*-amylbenzene from benzylmagnesium chloride and *n*-butyl *p*-toluenesulfonate, Gilman and Robinson, *Org. Syntheses*, **10**, 4 (1930), and the preparation of a series of *p*-bromoalkylbenzenes (ref. 44*b*).

46*a*. Gilman and Beaber, *J. Am. Chem. Soc.*, **45**, 839 (1923). *b*. Bachman, *ibid.*, **57**, 382 (1935).

47. Peacock and Tha, *J. Chem. Soc.*, 2303 (1928).

48. Tabern and Volwiler, *J. Am. Chem. Soc.*, **56**, 1141 (1934).

49*a*. Clemo and Tenniswood, *J. Chem. Soc.*, 2549 (1931). *b*. Prelog and Božičević, *Ber.*, **72B**, 1103 (1939).

50. Nair and Peacock, *J. Indian Chem. Soc.*, **12**, 318 (1935).

51*a*. Truchet, *Ann. chim.*, **16**, 309 (1931). *b*. Földi, U. S. pat., 1,897,795, *C.A.*, **27**, 2693 (1933).

52. Kenyon, Phillips, Pittman, Shackleton, Kahn, Yortson, and Cochinaras, *J. Chem. Soc.*, 1072 (1935).

53. Kenyon, Phillips, and Taylor, *ibid.*, 173 (1933); Phillips, *ibid.*, **127**, 2584 (1925).

54*a*. Freudenberg and Markert, *Ber.*, **60B**, 2447 (1927). *b*. Kenyon, Phillips, and Shutt, *J. Chem. Soc.*, 1663 (1935).

55. Suszko and Tomanek, *Rec. trav. chim.*, **52**, 18 (1933).

56. Simon and Frèrejacque, *Compt. rend.*, **178**, 1282 (1924).

57. Anschütz, *Ann.*, **415**, 75 (1918); see also Chapter III on sulfonation reactions.

58*a*. Schiff, *Ann.*, **173**, 171 (1875). *b*. Bradley and Robinson, *J. Chem. Soc.*, 1484 (1934).

59. Otto, *Ber.*, **19**, 1832 (1886).

60. Ferns and Lapworth, *J. Chem. Soc.*, **101**, 279 (1912).

61. Freudenberg and Hess, *Ann.*, 448, 121 (1926).

62. List and Stein, *Ber.*, **31**, 1662 (1898); Remsen and Humphreys, *Am. Chem. J.*, **30**, 294 (1903).

63*a*. Ullmann and Nádai, *Ber.*, **41**, 1871 (1908); Ullmann, German pat., 194,951, *Chem. Zentr.*, I, 1115 (1908). *b*. Sen, *Proc. Natl. Acad. Sci. India*, **7**, 218 (1937).

64. Borsche and Scholten, *Ber.*, **50**, 596 (1917).

65. Duisberg, Hentrich, and Zeh, U. S. pat., 1,646,785, *C.A.*, **22**, 243 (1928); see also British pat., 235,598, *C.A.*, **20**, 917 (1926).

66. von Wacek and Schopfer, *Oesterr. Chem.-Ztg.*, 40, 63 (1937).

67. Groves, Turner, and Sharp, *J. Chem. Soc.*, 512 (1929); Henley and Turner, *ibid.*, 928 (1930); Curd and Robertson, *ibid.*, 1166 (1933).

68. Bell, *J. Chem. Soc.*, 609 (1931).

69. Borsche and Feske, *Ber.*, **59B**, 683 (1926).

70. Simons, Archer, and Randall, *J. Am. Chem. Soc.*, **62**, 485 (1940).

71. Gilman, Beaber, and Meyers, *ibid.*, 47, 2048 (1925).

72. Gilman and Robinson, *Bull. soc. chim.*, **45**, 635 (1929).

73. Mine, *J. Chem. Soc. Japan*, **55**, 905, 1087 (1934); *C.A.*, **29**, 5427 (1935).

74. Bradfield and Jones, *J. Chem. Soc.*, 2903 (1931).

75. Hazlet, *J. Am. Chem. Soc.*, **59**, 1087 (1937).

76. Bell and Kenyon, *J. Chem. Soc.*, 3044 (1926).

77. Raschig, German pat., 233,631, *Chem. Zentr.*, **I**, 1388 (1911); *Frdl.*, **10**, 163

78. Schiaparelli, *Gazz. chim. ital.*, **11**, 74 (1881); Gilliard, Monnet, and Cartier, German pat., 91,314, *Frdl.*, **4**, 40.
79. Maeda, *J. Pharm. Soc. Japan*, No. 437,551 (1918); *C.A.*, **12**, 2197 (1918).
80. For references to other nitrations, see Table XXI.
81. A.-G., für Anilinfabrik, German pat., 185,547, *Chem. Zentr.*, II, 863 (1907); Badische Anilin- und Sodafabrik, German pat., 162,322, *Chem. Zentr.*, II, 726 (1905).
82. Werner, *Ann.*, **322**, 163 (1902).
83. Green, Marsden, and Scholefield, *J. Chem. Soc.*, **85**, 1433 (1904).
84. Chem. Fabr. Schering, German pat., 80,498, *Frdl.*, **4**, 1284.
85. Chem. Fabr. Schering, German pat., 82,747, *Frdl.*, **4**, 1286.
86. Ullmann and Loewenthal, *Ann.*, **332**, 64 (1904); see also Lesslie and Turner, *J. Chem. Soc.*, 2021 (1932).
87. Challenor and Ingold, *ibid.*, **123**, 2066 (1923).
88. Bell, *ibid.*, 1981 (1930).
89. Raiford and Lankelma, *J. Am. Chem. Soc.*, **47**, 1122 (1925); Raiford and Grosz, *ibid.*, **53**, 3420 (1931).
90. Friedländer and Schenck, *Ber.*, **47**, 3046 (1914).
91. J. R. Geigy, A.-G., British pat., 491,434, *C.A.*, **33**, 1520 (1939).

SULFONIC ANHYDRIDES

1. Billeter, *Ber.*, **38**, 2016 (1905).
2. See also Abrahall, *J. Chem. Soc.*, **49**, 692 (1886); Hübner, *Ann.*, **223**, 244 (1884).
3. Meyer and Schlegl, *Monatsh.*, **34**, 569 (1913); Meyer, *ibid.*, **36**, 721 (1915).
4. Hurtley and Smiles, *J. Chem. Soc.*, 1821 (1926).
5. Holleman, Choufoer, and Alozery, *Rec. trav. chim.*, **48**, 1075 (1929).
6. Baroni, *Atti accad. Lincei*, **17**, 1081 (1933).
7. Sohon, *Am. Chem. J.*, **20**, 258 (1898).
8. Taverne, *Rec. trav. chim.*, **39**, 542 (1920).
9. Fahlberg and Barge, *Ber.*, **22**, 757 (1889).

10*a*. Clark and Dreger, *Org. Syntheses*, 9, 80 (1929). *b*. Cobb, *Am. Chem. J.*, **35**, 502 (1906). *c*. White and Acree, *J. Am. Chem. Soc.*, **41**, 1197 (1919).

11*a*. Cornwell, *ibid.*, **54**, 819 (1932). *b*. Duin, *Rec. trav. chim.*, **40**, 724 (1921).

12. Heitman, *J. Am. Chem. Soc.*, **34**, 1591 (1912).
13. Twiss, U. S. pat., 1,760,328, *C.A.*, **24**, 3518 (1930); Twiss and Farinholt, *J. Am. Chem. Soc.*, **58**, 1561 (1936); Boyd and Rowe, *ibid.*, **52**, 4954 (1930).
14. List and Stein, *Ber.*, **31**, 1648 (1898).

15*a*. Cobb, *Am. Chem. J.*, **35**, 498 (1906). *b*. Cobb and Fuller, *ibid.*, **45**, 605 (1911).

16*a*. Remsen and Saunders, *ibid.*, **17**, 347 (1895). *b*. Fritzsch, *Ber.*, **29**, 2288 (1896). *c*. List and Stein, *Ber.*, **31**, 1664 (1898).

17. Sachs, *Ber.*, **37**, 3252 (1904).
18. White and Acree, *J. Am. Chem. Soc.*, **41**, 1190 (1919); Orndorff and Sherwood, *ibid.*, **45**, 486 (1923).
19. Orndorff and Purdy, *J. Am. Chem. Soc.*, **48**, 2212 (1926); Orndorff and Cornwell, *ibid.*, **48**, 981 (1926); Orndorff and Fuchs, *ibid.*, **48**, 1939 (1926).

20. Remsen, *Am. Chem. J.*, **6**, 180 (1884); Remsen and Hayes, *ibid.*, **9**, 372 (1887); Remsen and Linn, *ibid.*, **11**, 73 (1889); Fahlberg and Barge, *Ber.*, **22**, 754 (1889); Blackshear, *Am. Chem. J.*, **14**, 455 (1892); White, *ibid.*, **17**, 545 (1895); Remsen and McKee, *ibid.*, **18**, 802 (1896); Sisley, *Bull. soc. chim.*, [3] **17**, 822 (1897).

21. Orndorff and Vose, *J. Am. Chem. Soc.*, **46**, 1896 (1924).

22. Harden and Drake, *ibid.*, **51**, 562, 2278 (1929); Dunning and Farinholt, *ibid.*, **61**, 804 (1929); Boyd and Rowe, *ibid.*, **52**, 4954 (1930).

23. White and Acree, *ibid.*, **39**, 648 (1917); **40**, 1092 (1918); Lubs and Acree, *ibid.*, **38**, 2772 (1916); Birge and Acree, *ibid.*, **41**, 1031 (1919).

24. White and Acree, *ibid.*, **41**, 1190 (1919).

25. Orndorff and Shapiro, *ibid.*, **46**, 2856 (1924).

26. See standard reference books on determination of hydrogen ions such as the "Determination of Hydrogen Ions," by Clark, Williams and Wilkins Co., Baltimore, 1928; "Hydrogen Ions," Britton, D. van Nostrand Co., New York, 1929; "*p*H and Electrotitrations," Kolthoff, John Wiley & Sons, New York, 1931.

27. Snowden, *Arch. Intern. Med.*, **28**, 603 (1921); Gittings and Mitchell, *Am. J. Diseases Children,* **14**, 174 (1917); Lundsgaard and Moller, *Acta Med. Scand.*, **63**, 242 (1926), and many subsequent articles.

CHAPTER VI

DERIVATIVES OF AROMATIC SULFONIC ACIDS. 2 SULFONAMIDES AND RELATED COMPOUNDS

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SULFONAMIDES

Most aromatic sulfonic acids have been characterized by conversion into sulfonamides. The melting points of the amides and anilides obtained from the corresponding sulfonyl halides by treatment with ammonia and aniline have been listed earlier in Tables II to XVII of Chapter V. N-Substituted amides other than the anilides have been prepared for relatively few sulfonic acids and are chiefly of interest in identifying or preparing the amines except for sulfanilamide derivatives where the therapeutic activity is the center of interest. Because of these considerations and since a comprehensive review of sulfanilamide derivatives has appeared recently[1a] the N-substituted amides are not listed here in tabular form.

Entirely aside from their usefulness as derivatives and therapeutic agents, sulfonamides are of interest for their chemical properties. Their alkali solubility, difficulty of hydrolysis, and the replacement of amide hydrogens by various groups have been much studied. The interesting properties of the halogen compounds of the Chloramine-T type and of saccharin have instigated investigations on numerous related substances. The therapeutic value of sulfanilamide derivatives also has been responsible for a number of interesting developments in sulfonamide chemistry.

PREPARATION OF SULFONAMIDES

A few simple sulfonamides have been obtained by methods other than the action of ammonia upon a sulfonyl halide. Benzenesulfonyl isocyanate is readily decomposed by water to yield benzenesulfonamide.[1b] The reduction of benzenesulfonazide with zinc and acetic acid

$$C_6H_5SO_2NCO + H_2O \rightarrow C_6H_5SO_2NH_2 + CO_2$$

produces the amide as the final product.[2] Heating ammonium benzenesulfonate gives a small yield of the amide[3] the reaction lacking the practical value it has in the preparation of the carboxylic acid amides. The hydroxylammonium salts of benzene- and *p*-toluenesulfinic acids are converted by heating to 100–110° into the sulfonamides.[4] Attempts to prepare a sulfinhydroxamic acid by the action of

$$C_6H_5SO_2NH_3OH \rightarrow C_6H_5SO_2NH_2 + H_2O$$

hydroxylamine upon a sulfinyl chloride or sulfinamide also gave only the sulfonamide.[4b]

Preparation of N-Substituted Sulfonamides. The preparation of the sulfonamides from the common sulfonyl chlorides (including benzene- and the *p*-bromo- and three nitrobenzenesulfonyl chlorides, *p*-toluenesulfonyl chloride, and *β*-naphthalenesulfonyl chloride—reactions of acetanilidesulfonyl chloride are mentioned a little later), and primary,[5,6] or secondary[6,7] aliphatic amines including cyclic amines such as piperidine[6b,d;8] and polymethylenediamines[9] has been effected under a variety of experimental conditions. The reaction may be brought about in an inert solvent such as benzene or ether employing two equivalents of amine for one of the sulfonyl chloride, or in the presence of aqueous alkali where only one equivalent of amine is necessary. If the amine or acid chloride is a solid the addition of an organic solvent immiscible with water is desirable. Alternatively the reaction may be carried out in alcoholic sodium acetate or in pyridine solution. These experimental procedures are obviously interchangeable. The sulfonamides of aniline,[10] its nuclear derivatives,[11] the toluidines and xylidines and their nuclear derivatives,[12] and of N-alkylarylamines[13] have been similarly prepared. Derivatives of a few diarylamines,[14] aminobiphenyls,[15] and naphthylamines[16] have also been placed on record. The sulfonamides prepared from aliphatic amino acids and aromatic sulfonyl chlorides have been intensively investigated.[17] Many peptides have also been characterized by conversion into sulfonamides by the use of β-naphthalenesulfonyl chloride.[18] A few aromatic aminocarboxylic acids [19] together with their esters and amides and also a number of aminoketones [20] of various types have been converted into sulfonamides.

The starting point for preparing many of the sulfanilamide derivatives has been acetanilide-*p*-sulfonyl chloride [1] (N^4-acetylsulfanilyl chloride). This reacts with ammonia or amines in alkaline solution without loss of the acyl group which is subsequently removed usually by acid hydrolysis. Recently [21a] it has been reported that aniline-*p*-sulfonyl chloride can be prepared and that this gives sulfanilamide directly with ammonia. The action of ammonia on *p*-chlorobenzenesulfonyl chloride also gives sulfanilamide.[21c] Phenolic sulfonamides may be prepared advantageously from phenolsulfonyl fluorides which are more stable than the chlorides.[21b] Polymeric sulfonamides have been prepared in which aromatic nuclei are linked together by the sulfonimide (SO_2NH) group.[21d]

Alkylation and Arylation Methods of Preparing Sulfonamides. Many N-alkylsulfonamides have been prepared by the action of alkyl halides or sulfates in aqueous or alcoholic alkali upon amides that have one or two replaceable hydrogens.[22]

$$C_6H_5SO_2N(K)C_6H_5 + CH_3I \rightarrow C_6H_5SO_2N(CH_3)C_6H_5 + KI$$

One recently [23] described procedure calls for refluxing *p*-toluenesulfonmethylamide with concentrated sodium hydroxide and 20% excess *n*-butyl bromide until no more water is deposited in an automatic separator. In another example [24] an 88% yield of the dimethylamide was obtained by the action of methyl sulfate and alkali upon N^4-acetylsulfanilamide. It has been claimed [25] that *p*-toluenesulfonamide is monoalkylated by sodium ethyl sulfate or benzyl chloride in the presence of sodium or calcium carbonate at 170–200°. Xylenesulfonamides have been alkylated by heating with methyl or ethyl chloride and aqueous sodium hydroxide under pressure.[26]

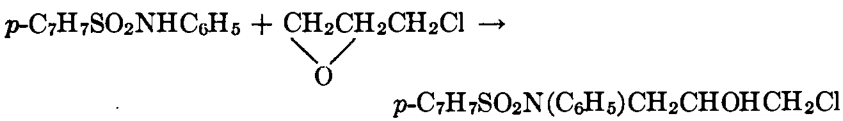
p-Toluenesulfonamide reacts readily with an α-halogenated fatty acid in alkaline solution and the resulting product can be alkylated on the nitrogen.[27] Since the resulting amide can be hydrolyzed these reactions are of value in amino acid synthesis.

$$ClCH_2COONa + p\text{-}C_7H_7SO_2NHNa \rightarrow p\text{-}C_7H_7SO_2NHCH_2COONa + NaCl$$

$$p\text{-}C_7H_7SO_2NHCH_2COONa + CH_3I + NaOH \rightarrow C_7H_7SO_2N(CH_3)CH_2COONa + NaI + H_2O$$

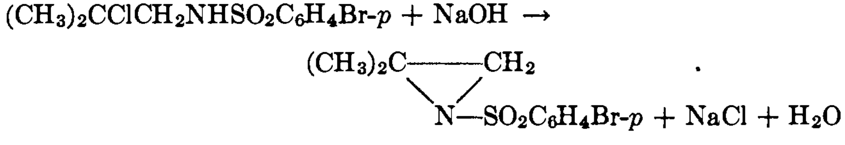
A number of sulfonamides have been shown to react readily with ethylene chlorohydrin or oxide.[28] In the case of epichlorohydrin[29a] the oxide linkage reacts first but the product was difficult to purify indicating side reactions. The product from the reaction of p-toluenesulfonamide and glycerol-1,3-dichlorohydrin has been used as an intermediate in the preparation of a plastic composition.[29b] Similar reactions of sugar derivatives also have been reported.[30] The methyl ether of ethylene chlorohydrin reacts normally with p-toluenesulfonamide and alkali.[31]

$$p\text{-}C_7H_7SO_2N(Na)C_2H_5 + ClCH_2CH_2OH \rightarrow p\text{-}C_7H_7SO_2N(C_2H_5)CH_2CH_2OH + NaCl$$



$$p\text{-}C_7H_7SO_2NHC_6H_5 + \underbrace{CH_2CH}_{O}CH_2Cl \rightarrow p\text{-}C_7H_7SO_2N(C_6H_5)CH_2CHOHCH_2Cl$$

The alkylating action of polymethylene halides is of interest. Ethylene bromide[32a, b] reacts with benzenesulfonamide in alkaline solution to give dibenzenesulfonethylenediamide and dibenzenesulfonpiperazide. In this connection the results of Adams and Cairns[32c] are of interest. They found that p-bromobenzenesulfon-β-chloroethylamide with aqueous alkali gave only the sulfonyl derivative of ethanolamine, whereas the sulfonamide derived from 2-chloro-2-methylpropylamine reacted to give a derivative of ethyleneimine.

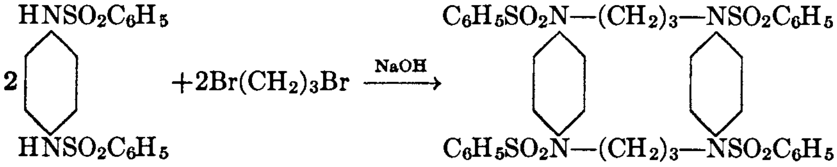


$$(CH_3)_2CClCH_2NHSO_2C_6H_4Br\text{-}p + NaOH \rightarrow \underbrace{(CH_3)_2C\text{—}CH_2}_{N}\text{—}SO_2C_6H_4Br\text{-}p + NaCl + H_2O$$

Similar ring closure reactions have been reported for compounds obtained by the addition of N-halogen sulfonamides to olefins (see p. 610). Trimethylene bromide[32,33] with p-toluenesulfonamide produces mostly p-toluenesulfoncyclotrimethyleneamide together with a little of the bis-trimethylenediamine derivative and other by-products.

$$Br(CH_2)_3Br \xrightarrow{p\text{-}C_7H_7SO_2NH_2 + NaOH} p\text{-}C_7H_7SO_2N(CH_2)_3 + p\text{-}C_7H_7SO_2N(CH_2CH_2CH_2)_2NSO_2C_7H_7\text{-}p$$

Alkylation of dibenzenesulfon-p-phenylenediamide with trimethylene bromide[34] is reported to yield the curious cyclic compound shown in the accompanying equation. It seems possible that the product was actually a polymer.



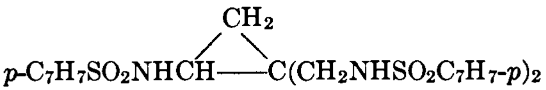
Tetramethylene bromide gives an 80% yield of the sulfonamide of pyrollidine.[35] Since this can be hydrolyzed to pyrollidine, it serves as a useful intermediate for obtaining the free base. Hexamethylene bromide yields a mixture of the sulfonamides of the mono and diamines.[36] the fourteen-atom ring compound not being isolated.

$$Br(CH_2)_6Br \xrightarrow{p\text{-}C_7H_7SO_2NH_2+KOH}$$
$$p\text{-}C_7H_7SO_2N(CH_2)_6 + p\text{-}C_7H_7SO_2NH(CH_2)_6NHSO_2C_7H_7\text{-}p$$

Pentaerythrityl bromide[37] reacts with the sodium salt of p-toluenesulfonamide at 210° to give a mixture of products. The acetate of

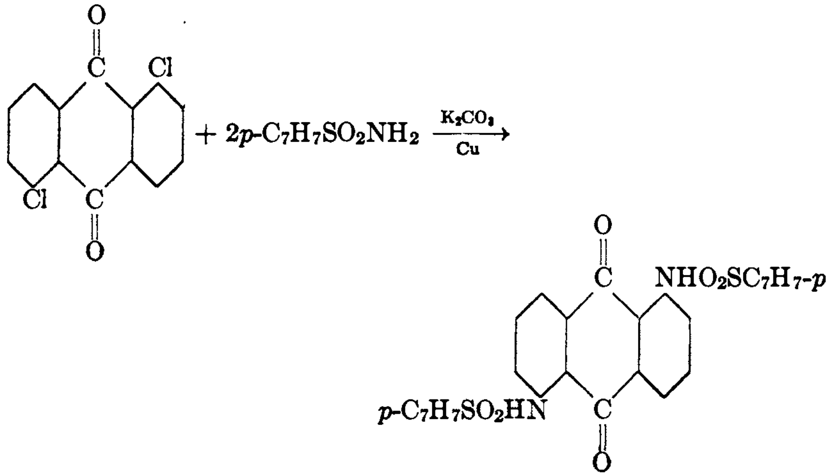
$$C(CH_2Br)_4 \xrightarrow{p\text{-}C_7H_7SO_2NHNa}$$
$$C(CH_2NHSO_2C_7H_7\text{-}p)_4 + p\text{-}C_7H_7SO_2N(CH_2)_2C(CH_2NHSO_2C_7H_7\text{-}p)_2$$

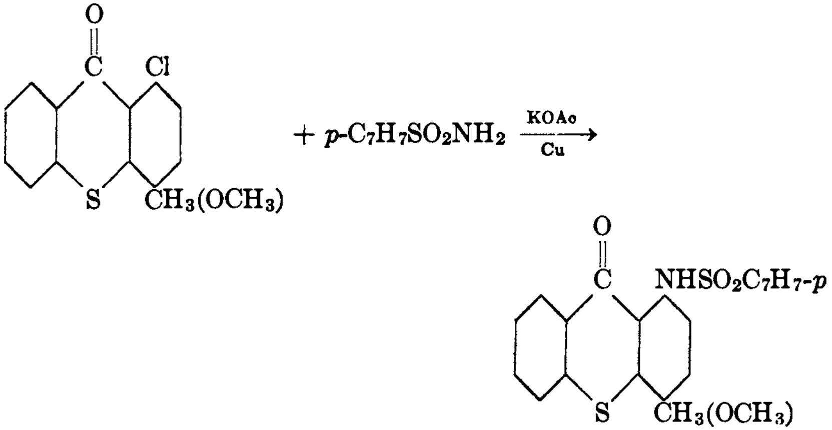
the tribromide gives two other substances whose formulas are shown.



$$p\text{-}C_7H_7SO_2N(CH_2)_2C(CH_2)_2NSO_2C_7H_7\text{-}p$$

The preparation of the sulfonamide of an arylamine by the reaction of a simple amide with an aromatic compound containing an activated halogen has been frequently described.[38] Most of the available examples involve an alpha-halogenated anthraquinone or thioxanthone. The 1-amino-2-methyl-4-bromoanthraquinone obtained by bromination of the amine reacts readily with p-toluenesulfonamide to give a 95% yield of 1-amino-2-methyl-4-p-toluenesulfonamidoanthraquinone which can be hydrolyzed in a 97% yield to the 1,4-diaminoanthraquinone. The reaction is not limited to *alpha* bromo compounds since 1-amino-3-bromo-2-anthraquinonecarboxylic acid also reacts with p-toluenesulfonamide in the presence of copper acetate to give an amide which on hydrolysis yields 1,3-diamino-2-anthraquinonecarboxylic acid. The equations show the behavior of typical chlorine compounds.





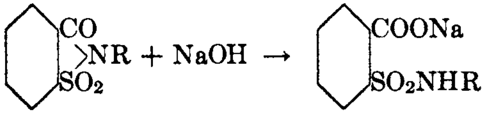
Miscellaneous Syntheses of Sulfonamides. It has been claimed[39] that sulfonamides of secondary amines can be prepared by condensing a dialkylsulfamyl chloride with an anilide.

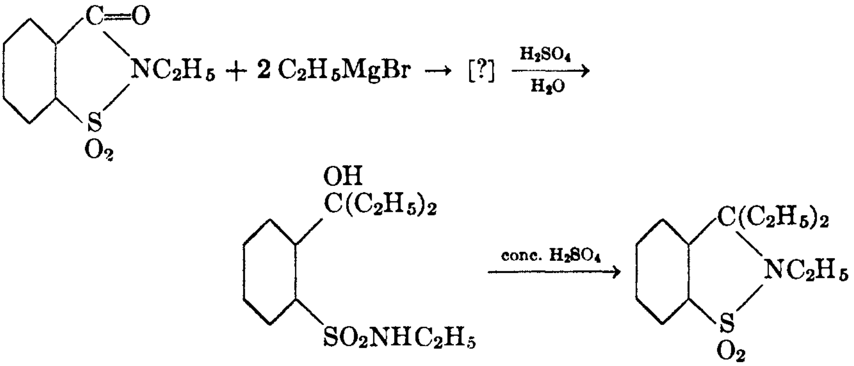
$$CH_3CONHC_6H_5 + (CH_3)_2NSO_2Cl \xrightarrow{AlCl_3} CH_3CONHC_6H_4SO_2N(CH_3)_2 + HCl$$

The majority of the monosulfonamides of aromatic diamines[40] have been obtained by reduction of nitro or azosulfonamides. A novel method for preparing the mono-*p*-toluenesulfonamide of benzidine and similar diamines consists in the rearrangement of *p*-toluenesulfonhydrazobenzene with concentrated sulfuric acid.[41]

$$C_6H_5NHN(O_2SC_7H_7\text{-}p)C_6H_5 \xrightarrow{H_2SO_4} p\text{-}C_7H_7SO_2NHC_6H_4C_6H_4NH_2$$

Saccharin has served as the starting point for the preparation of a number of alkylsulfonamides. N-Alkylsaccharins undergo partial hydrolysis with alcoholic alkali to form *o*-carboxybenzenesulfonamides,[42] these reverting to the saccharin derivatives upon heating or treatment with acid. Several alkylsulfonamides have been obtained by the action of a Grignard reagent upon an N-alkylsaccharin followed by acid hydrolysis.[43] The nature of the intermediate is not certain. Apparently it is not the sultam, which is produced by action of a dehydrating agent on the amide. In addition to the product shown in the equation, sulfonamides have been prepared by this method from N-methylsaccharin with ethyl, isopropyl, and isoamylmagnesium bromides, and from N-ethylsaccharin with isopropyl and isoamylmagnesium bromides.





Sultam

The preparations of some other sulfonamides are described in the section on substitution reactions of the sulfonamides.

PROPERTIES AND REACTIONS OF SULFONAMIDES

Physical Properties. The amides of aromatic sulfonic acids are with relatively few exceptions colorless crystalline solids that are only slightly soluble in cold water, this solvent or alcohol serving well for the purification of most of them. At room temperature 0.43 g. of benzenesufonamide dissolves in 100 g. of water[44] while *p*-toluenesulfonamide[45] dissolves to the extent of 0.2 g. at 9°.

It has been found that the sulfonamides are associated in benzene[46] and other[47] organic solvents, just as are the amides and anilides of carboxylic acids, provided there is a hydrogen attached to the amide nitrogen. It is unlikely that sulfonamides are associated in polar solvents.

The Raman spectra of benzenesulfonamide, sulfamic acid, and other compounds containing a nitrogen-sulfur linkage show a characteristic displacement believed[48] to be assignable to this particular valence bond. The absorption spectra[49] of *p*-toluenesulfonamide and its salts in the near infrared also have been determined.

Baroni[50] has reported the parachor for twenty-one sulfonamides and anilides at 200°. The values obtained are from 1 to 3 points below the calculated parachors but this discrepancy is not enough to indicate a deviation from the assumed structure which contains two semi-polar bonds.

The crystallographic properties of *o*-toluenesulfonamide[51] and for numerous *p*-toluenesulfonalkylamides[52] have been reported in detail. The heat of fusion[53] for *o*-toluenesulfonamide is 6700 cal. while for the *para* compound it is 5850 cal.

Solubility of Sulfonamides in Alkali. Few quantitative data on the acid properties of amides of various types are available. It has been observed[54a, b] that salts of sulfonamides are somewhat hydrolyzed in water as determined by their conductivity and extraction of the water solution with ether. Hydrolysis is slight in the case of tribromo and dinitrobenzenesulfonamide salts and N-benzoylbenzenesulfonamide salts are practically neutral. It has been observed[55] that sulfonanilides can be titrated with an error of less than 1% by dissolving in 0.1 *N* sodium hydroxide and back-titration with 0.1 *N* hydrochloric acid in the presence of barium chloride with phenolphthalein as the indicator. The procedure is not applicable if an hydroxyl or amino group is present in the molecule.

It was first remarked by Hinsberg[56] that the benzenesulfonalkylamides derived from a number of primary amines were soluble in alkali and that this made possible the separation of primary, secondary, and tertiary amines. Solonina[57] later observed that this separation method encountered two difficulties; many primary amines readily formed alkali-insoluble dibenzenesulfonamides, and even the monoamides of some amines did not dissolve readily. In particular those derived from *n*-heptylamine, camphylamine, and 2-aminoundecane were unaffected by dilute alkali. However, if concentrated sodium hydroxide is employed[58] benzenesulfon-*n*-heptylamide is converted completely into the crystalline sodium salt which is alkali insoluble. This indicated that the difference in the amides might be due in part to the difference in properties of their salts rather than their basic properties. Duden,[59] however, showed that 11% sodium hydroxide under a given set of conditions extracted 98% of the benzenesulfonethylamide from an ether solution whereas the *n*-heptyl compound practically all remained in the ether layer. Of course, two explanations may be given for these results. The distribution ratio of the amides between water and ether may be the important factor rather than their acidity. No data are available on either property.

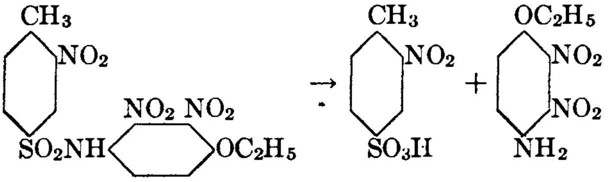
It has been found[60] that the benzene- and *p*-toluenesulfonamides derived from benzylamine, *o*- and *p*-methylbenzylamines, and β-phenylethylamine as well as a number of *p*-bromobenzenesulfonamides derived from aromatic amines[61] are nearly insoluble in alkali. On the other hand the nitrobenzenesulfonamides of both aliphatic and aromatic amines are alkali-soluble except for that obtained from *p*-bromoaniline and *m*-nitrobenzenesulfonyl chloride.[62] Since the disulfonamides from primary amines and these nitro compounds are decomposed by 12% potassium hydroxide or alcoholic sodium ethoxide the nitrobenzenesulfonamides seem to be the most suitable derivatives

$$(ArSO_2)_2NR + 2KOH \rightarrow ArSO_3K + ArSO_2NR^- + K^+$$

for identifying mixtures of amines. Hydrolysis of these amides is difficult, however, so that recovery of the free amines is not practical.

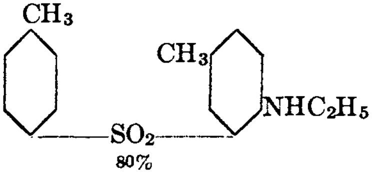
Hydrolysis of Sulfonamides. Since many of the sulfonamides from primary and secondary amines are separable by alkali, hydrolysis of these compounds is of interest as a means of obtaining pure amines. Sulfonamides are much less susceptible to hydrolysis, however, than are amides of carboxylic acids. Heating with concentrated hydrochloric acid in a sealed tube at a high temperature[54b,56,63] or refluxing for 12–36 hours[64] with 25% hydrochloric acid is necessary to complete the reaction. The latter more convenient method gives over 90% yields of recovered amine except for nitrobenzenesulfonamides. The amides of alkylarylamines hydrolyze more rapidly than those of the primary arylamines and a *m*-nitro group retards hydrolysis less than this group does in the *ortho* and *para* positions.

The behavior of the amides of aliphatic sulfonic acids is about the same as for the aromatic compounds. A variety of methanesulfonarylamides hydrolyze when refluxed for 6 hours with sulfuric acid made from equal parts of the concentrated acid and water.[65] The yields of recovered amines were from 70 to 80% of the theoretical amount. Hydrolysis of sulfonamides by letting them stand in concentrated sulfuric acid for an interval of a day to a week or more has been described as an excellent procedure in some instances.[66] A trinitration product of *p*-toluenesulfon-*p*-phenetidide undergoes cleavage[67] when heated at 100° with concentrated sulfuric acid.



The hydrolysis of certain amides by strong sulfuric acid is, however, complicated by the formation of rearrangement and sulfonation products. Amides of arylalkylamines are particularly prone to side reactions. Thus *p*-toluenesulfon-*p*-toluidide yields only the amine[68] with three to one sulfuric acid (acid to water by volume) while the N-methyl and ethyl derivatives give both sulfones and amines. With concentrated sulfuric acid the yield of sulfone reaches 80%. The

$p\text{-}C_7H_7SO_2N(C_2H_5)C_7H_7\text{-}p \rightarrow$



80%

[+ $p\text{-}C_7H_7NHC_2H_5 + C_7H_7SO_3H$]

effect of acid concentration has been investigated in more detail for N-methyl-*p*-toluenesulfon-*p*-anisidide.[69] Here 40% acid at 150° causes little hydrolysis, 60% acid produces a 60% yield of N-methyl-*p*-anisidine, while with 70% acid at 120° there is complete rearrangement to the sulfone. If the methyl group is absent 80% acid at 110° gives only 35% of the sulfone while with concentrated (d., 1.84) acid at 150° demethylation of the ether group, hydrolysis, sulfonation, and rearrangement all occur. In view of these results it seems unlikely that the patented process for sulfonating amines by treating their sulfonamides with sulfuric acid, which is claimed to both sulfonate and hydrolyze the amide, gives satisfactory yields of aminesulfonic acids.[70]

Sulfonamides derived from diarylamines[71] give essentially analogous results, *p*-toluenesulfonphenyl-*p*-tolylamide yielding two sulfones and a sulfonic acid when treated with concentrated sulfuric acid.

In a few instances sulfonamides have been found to undergo cleavage when heated with chlorosulfonic acid. This is not, strictly speaking, a hydrolysis but since the amine can be recovered from the reaction products it serves the same purpose. Benzenesulfondialkylamides[54b, 72] when heated with chlorosulfonic acid at 130–150° for 2 to 3 hours give 70% or less of the benzenesulfonyl chloride and a sulfamic acid from which a theoretical yield of the base may be obtained.

$$C_6H_5SO_2NR_2 + ClSO_3H \rightarrow C_6H_5SO_2Cl + R_2NSO_3H$$

$$R_2NSO_3H + 2NaOH \rightarrow Na_2SO_4 + R_2NH$$

Other amides behave similarly.[73] *p*-Toluenesulfon-*p*-toluidide with cold chlorosulfonic acid[74] yields *p*-toluenesulfonyl chloride and *p*-toluidinesulfonic acid. Another method of cleavage which falls in this same category is that produced merely by warming the amide with acetyl or chloroacetyl chloride.[75] This has been applied in preparing a number of amino acids. Simple amides, unfortunately, are not cleaved by this type of reagent, undergoing acylation.[76]

$$p\text{-}C_7H_7SO_2NHCH_2COOC_2H_5 + CH_3COCl \rightarrow p\text{-}C_7H_7SO_2Cl + CH_3CONHCH_2COOC_2H_5$$

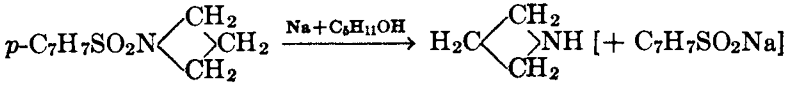
It has been reported that treatment of one complex amide with hydrogen bromide in acetic acid brought about disulfide formation and bromination of an aromatic nucleus.[29]

$$2p\text{-}C_7H_7SO_2N(C_6H_5)CH_2CH(OOCC_6H_5)CH_2OOCC_6H_5 + 6HBr \rightarrow (p\text{-}C_7H_7S)_2 + 2\ 2{,}4\text{-}Br_2C_6H_3NHCH_2CH(OOCC_6H_5)CH_2OOCC_6H_5 + Br_2 + 4H_2O$$

Heating sulfonamides with hydriodic acid also results in combined hydrolysis and reduction reactions.[77] The yield of amine is good if phosphonium iodide is present to remove the iodine as fast as it is formed. This method is particularly valuable in the recovery of optically active amino acids from their sulfonamides. Sulfonic acids are

$$ArSO_2NHCH_2COOH + 6HI \rightarrow ArSH + H_2NCH_2COOH + 3I_2 + 2H_2O$$

not affected by hydriodic acid, although acid chlorides are readily reduced. Amides of carboxylic acids are not reduced. Another procedure combining cleavage with reduction depends upon sodium and butyl or amyl alcohol.[82b, 78]



$$p\text{-}C_7H_7SO_2N\left\langle\begin{matrix}CH_2\\ \rangle CH_2\\ CH_2\end{matrix}\right. \xrightarrow{Na+C_5H_{11}OH} H_2C\left\langle\begin{matrix}CH_2\\ \rangle NH\\ CH_2\end{matrix}\right. [+ C_7H_7SO_2Na]$$

Sodium in liquid ammonia behaves similarly.[79b] In one instance zinc and sulfuric acid have been reported [79a] to effect such a change. However, *p*-toluenesulfonphenacylamide and γ-*p*-toluenesulfonamido-δ-ketocaproic acid cleave the other way with this reagent [79b] giving a high yield of *p*-toluenesulfonamide.

$$p\text{-}C_7H_7SO_2NHCH_2COC_6H_5 \xrightarrow[HCl]{Zn} p\text{-}C_7H_7SO_2NH_2 + C_6H_5COCH_3$$

Two other miscellaneous procedures involving acids may be mentioned. *m*-Nitrobenzenesulfonamide [80] has been converted to the acid by treatment with nitric acid and boiling the product with ethyl alcohol. It was observed by Rouiller [81] that a number of sulfonamides when heated with benzoic acid at 220° or above give the benzamidine sulfonates in fair yields.

Heating sulfonamides with strong alkali does not result in hydrolysis unless a nitro group is *ortho* or *para* to the sulfur.[82] The hydrolysis of these nitrobenzenesulfonamides occurs first between carbon and sulfur rather than sulfur and nitrogen.

$$o\text{-}O_2NC_6H_4SO_2NHC_6H_5 + 2NaOH \rightarrow o\text{-}O_2NC_6H_4ONa + C_6H_4NHSO_3Na + H_2O$$

$$C_6H_5NHSO_3Na + NaOH \rightarrow C_6H_5NH_2 + Na_2SO_3$$

In Table I is shown the extent to which various sulfonamides hydrolyze when heated with 80% sodium hydroxide. The nitro compounds were heated for 30 minutes and the others up to 4 hours.

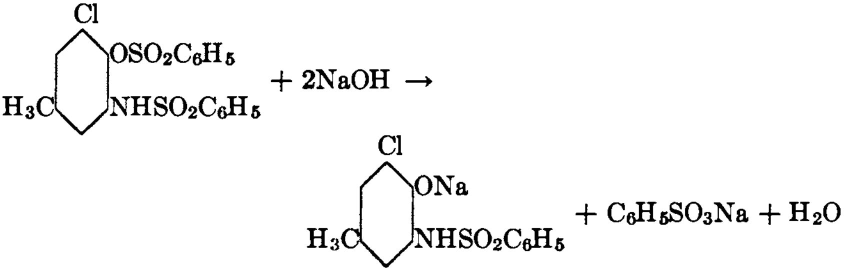
TABLE I

HYDROLYSIS OF SULFONAMIDES

Compound	Temp., °C.	Yield of Amine, %
$C_6H_5SO_2NHC_6H_5$	250	0
$2,4,6\text{-}(CH_3)_3C_6H_2SO_2NHC_6H_5$	170–225	0
$2,4,6\text{-}(CH_3)_3C_6H_2SO_2N(CH_3)C_6H_5$	185–225	0
$2,4\text{-}Br_2C_6H_3SO_2NHC_6H_5$	210–215	0.8
$2,4\text{-}Br_2C_6H_3SO_2N(CH_3)C_6H_5$	210–215	0.6
$2,4,6\text{-}Br_3C_6H_2SO_2NHC_6H_5$	210–215	5.3
$2,4,6\text{-}Br_3C_6H_2SO_2N(CH_3)C_6H_5$	210–215	3.4
$2,4\text{-}(O_2N)_2C_6H_3SO_2NHC_6H_5$	155	79
$2,4\text{-}(O_2N)_2C_6H_3SO_2N(CH_3)C_6H_5$	155	71

Heating the *p*-toluenesulfonamide of dihydroisoindole with 85% potassium hydroxide [83] gave toluene and other products but not the amine. The behavior of the benzylmethylamide [84] is somewhat different, benzalmethylamine, $C_6H_5CH{=}NCH_3$, being one of the products. Benzenesulfonanilide with fused moist alkali gave aniline as one product.

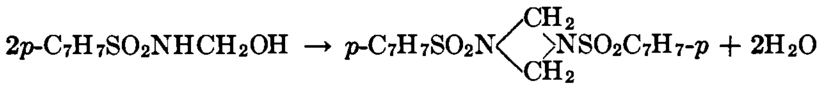
An interesting comparison of the behavior of sulfonates and sulfonamides toward alkali is shown in the reaction of the dibenzenesulfonyl derivative of 6-chloro-4-methyl-2-aminophenol toward boiling 10% sodium hydroxide.[85a] A sulfonyl derivative of ethyleneimine reacts with n-butylamine,[85b] presumably as indicated.



$$ArSO_2N(CH_2)_2 + C_4H_9NH_2 \rightarrow ArSO_2NHCH_2CH_2NHC_4H_9$$

Condensation of Sulfonamides with Aldehydes. The reaction of formaldehyde with sulfonamides gives a variety of products, including plasticizers and resins. It was reported many years ago that benzenesulfonamide[86] gives with formaldehyde two products having the formulas $(C_7H_7SO_2N)_2$ and $(C_7H_7SO_2N)_3$. By heating the amide and formaldehyde in aqueous solution made slightly alkaline with potassium carbonate[87] dibenzenesulfonylmethylenediamine, $(C_6H_5SO_2NH)_2$-CH_2 is obtained. In the case of p-toluenesulfonamide the reaction has been stopped at its initial stage to give the hydroxymethylamide. Heating with benzene converts this into the methylenediamine derivative which is accompanied by some dimeric anhydroformaldehyde-p-toluenesulfonamide. The latter is the chief product when the hydroxymethylamide is treated with a dehydrating agent in alcohol.

$$p\text{-}C_7H_7SO_2NH_2 + HCHO \rightarrow p\text{-}C_7H_7SO_2NHCH_2OH$$



$$2p\text{-}C_7H_7SO_2NHCH_2OH \rightarrow p\text{-}C_7H_7SO_2N\begin{matrix} CH_2 \\ \\ CH_2 \end{matrix}NSO_2C_7H_7\text{-}p + 2H_2O$$

The only product isolated from the condensation of the aldehyde and p-toluenesulfonamide in alcohol in the presence of hydrochloric acid was the trimer, believed to be 1,3,5-tri-p-toluenesulfonylhexahydro-*sym*-triazine.[88] The yield was 40%. The same product was obtained more readily from the action of trioxymethylene with the sulfonamide in glacial acetic acid in the presence of sulfuric acid.

The trimer is formed in 80% yield as the sole product of the reaction of the sulfonyl chloride with hexamethylenetetramine in alkaline solution. The reaction of formaldehyde with *o*-toluenesulfonamide has been shown to give the methylenediamine derivative[87] as well as the dimer and trimer,[88] depending on the reaction conditions. Condensing *p*-toluenesulfonmethylamide or the phenylamide with formaldehyde gives the methylene derivatives as might be expected. Two products were isolated from the reaction of sulfanilamide with formaldehyde. It was suggested[89] that they had the formulas $CH_2{=}NC_6H_4SO_2NH_2$ and $H_2NC_6H_4SO_2NHCH_2OH$.

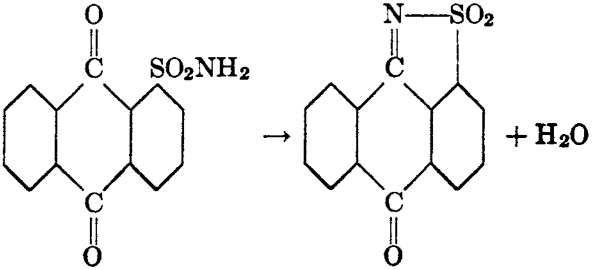
A number of patents[90] have been granted on the preparation and use of various sulfonamide-formaldehyde products that are claimed to be of value as plasticizers, resins, and tanning agents.[91] It has been stated by Walter and co-workers[92] that resins from disulfonamides can be made infusible and insoluble whereas monosulfonamide resins cannot. The resin from the diamide of *p*-sulfobenzoic acid is hydrophilic whereas disulfonamide resins are hydrophobic.[93] Resins have also been prepared from *sym*-benzenetrisulfonamide and phenol-2,4-disulfonamide.[94]

In an earlier patent[95] it was claimed that a resin can be obtained from *p*-toluenesulfonamide and furfural but this reaction has apparently not been studied further.

A reaction that is related to the one between an aldehyde and a sulfonamide is that of sodium hydroxymethanesulfonate (formaldehyde sodium bisulfite) with benzenesulfonamide.[96]

$$C_6H_5SO_2NH_2 + HOCH_2SO_3Na \rightarrow C_6H_5SO_2NHCH_2SO_3Na + H_2O$$

Apparently no reaction of a ketone with a sulfonamide is known except where the two groups are in the same molecule.[97] Anthraquinone-1-sulfonamide loses water readily.



Reaction of Sulfonamides with Diazonium Salts. It was first observed by Hinsberg[98] that benzenediazonium chloride condenses with benzenesulfonamide in dilute alkaline solution.

$$C_6H_5N_2Cl + C_6H_5SO_2NHNa \rightarrow C_6H_5SO_2NHN{=}NC_6H_5 + NaCl$$

If the concentration of hydroxyl ions is appreciable there is obtained a diazo compound[99] identical with that produced by the action of a diazonium salt upon a sodium sulfinate.[100]

$$p\text{-}C_7H_7N_2Cl + C_6H_5SO_2Na \rightarrow C_6H_5SO_2N{=}NC_7H_7\text{-}p + NaCl$$

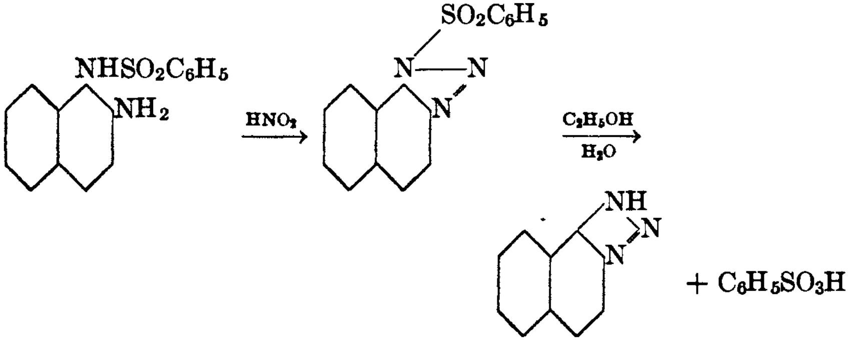
This result has been explained by demonstrating[101] that in alkaline

$$ArSO_2NHN{=}NAr' \xrightarrow{OH^-} ArSO_2\overset{-}{N}{-}N{=}N{-}Ar' \rightarrow ArSO_2^- + Ar'N_3$$

solution the compound first formed is unstable. The resulting sulfinate may then react as already indicated. Acid hydrolysis of the diazoamide proceeds quite differently; the products are the amide, nitrogen, and phenol. Methylation, interestingly enough, adds the alkyl group on the nitrogen adjacent to the aryl nucleus.

$$ArSO_2NHN{=}N{-}Ar' + CH_3I \rightarrow ArSO_2NHN{=}N(CH_3){-}Ar' + [HI]$$

Diazo compounds obtained from aliphatic sulfonamides react in the same manner as the aromatic derivatives.[102] Sulfonanilides containing a *para* substituent, in general, give diazoamino derivatives,[103] $ArSO_2N(Ar')N{=}NC_6H_5$, but no information on their stability was given. 1-Benzenesulfonamido-2-naphthylamine and similar compounds with nitrous acid yield heterocyclic compounds[104] of the diazoamide type. When treated with ethyl alcohol the sulfonyl group is in general easily removed; however, this is not true for the product obtained from



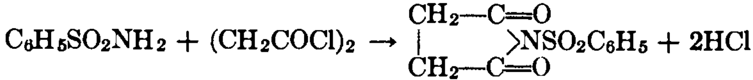
2-benzenesulfonamido-1-naphthylamine.

Reaction of Sulfonamides with Acyl and Sulfonyl Halides. Aside from saccharin and its analogs and derivatives which are given separate treatment (see p. 616) only a few acylsulfonamides have been prepared, and their reactions have not been investigated to an appreciable extent. Benzenesulfonamide reacts with benzoyl chloride[105] or *p*-isopropylbenzoyl chloride when the mixture is heated to 145°.

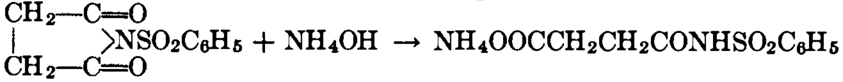
$$C_6H_5SO_2NH_2 + C_6H_5COCl \rightarrow C_6H_5SO_2NHCOC_6H_5 + HCl$$

A few other similar reactions have been mentioned.[106] Compounds such as N-acetyl-*p*-toluenesulfonethylamide are claimed to be suitable for use as plasticizing agents for cellulose derivatives.[107]

Succinyl chloride and benzenesulfonamide at 200° give the cyclic imide[105] whereas succinic anhydride with the amide and phosphorus oxychloride yield the disulfonylsuccinamide.[108]



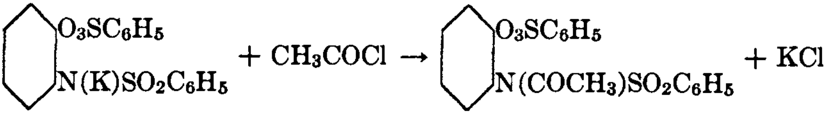
$$C_6H_5SO_2NH_2 + (CH_2COCl)_2 \rightarrow \left.\begin{array}{l} CH_2-C{=}O \\ | \\ CH_2-C{=}O \end{array}\right\rangle NSO_2C_6H_5 + 2HCl$$



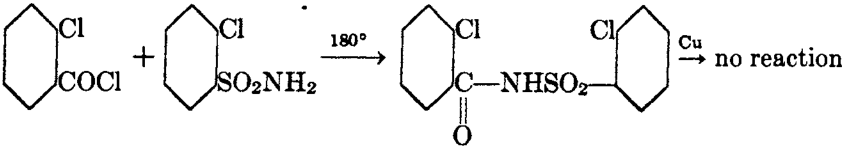
$$\left.\begin{array}{l} CH_2-C{=}O \\ | \\ CH_2-C{=}O \end{array}\right\rangle NSO_2C_6H_5 + NH_4OH \rightarrow NH_4OOCCH_2CH_2CONHSO_2C_6H_5$$

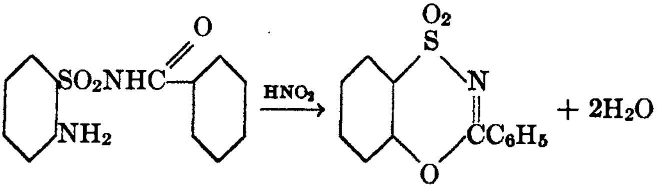
With ammonia the imide undergoes partial hydrolysis as shown. Phthalyl chloride reacts with benzene- or *p*-toluenesulfonamide[109] in boiling toluene, but the sulfonylphthalimide could not be obtained by heating the amide with phthalic anhydride, or from phthalimide and the sulfonyl chloride. A whole series of sulfonylimides has been prepared from the action of phthalic anhydride upon sulfonamides in the presence of phosphorus oxychloride.[108]

The solid potassium salt of *o*-benzenesulfonamidophenyl benzenesulfonate[110] yields the acyl derivative when treated with an acid chloride.

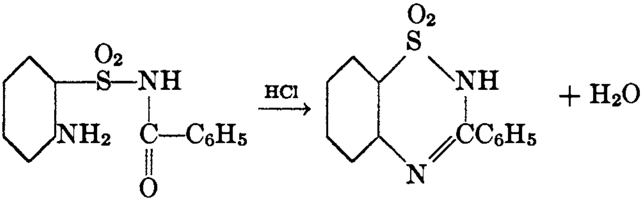


Attempts to bring about ring closure by heating N-*o*-chlorobenzoyl-*o*-chlorobenzenesulfonamide[111] with copper powder were unsuccess-

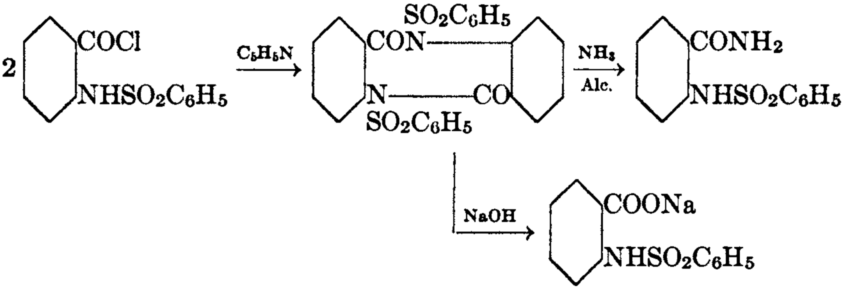




ful. However, *o*-aminobenzenesulfonylbenzamide is converted into a heterocyclic compound through the diazo reaction.[112] Ring closure to a different heterocycle was effected through the action of hydrogen chloride.



o-Benzenesulfonamidobenzoyl chloride when heated with pyridine gives a quantitative yield of a bimolecular product.[113] This undergoes decomposition with alkali or alcoholic ammonia.



In the presence of alkali, sulfonamides react readily with sulfonyl chlorides to give the disulfonimides. These compounds, in fact, frequently interfere in the identification of primary amines by the Hinsberg reaction. Thus sodium or silver benzenesulfonamate[114] reacts readily with a sulfonyl chloride. The same compound results from

$$C_6H_5SO_2NHNa + C_6H_5SO_2Cl \rightarrow (C_6H_5SO_2)_2NH + NaCl$$

the reduction of dibenzenesulfonylhydroxyimide with sulfur dioxide.[115]

$$(C_6H_5SO_2)_2NOH + H_2SO_3 \rightarrow (C_6H_5SO_2)_2NH + H_2SO_4$$

Disulfonyl derivatives of aromatic amines have been investigated by Bell.[116] The *p*-toluenesulfonamides of aniline, β-naphthylamine, and *p*-aminobiphenyl show little tendency to react with another mole of *p*-toluenesulfonyl chloride but the nitroanilines give the disulfonyl derivatives when heated in pyridine solution with the sulfonyl chloride. Two moles of *m*-nitrobenzenesulfonyl chloride react with aniline after heating several days in pyridine.

The disulfonanilides are readily cleaved by the action of piperidine. Where two different sulfonyl groups are present only one may be removed.

$$(p\text{-}CH_3C_6H_4SO_2)_2NC_6H_4NO_2\text{-}p + C_5H_{10}NH \rightarrow$$

$$p\text{-}CH_3C_6H_4SO_2NHC_6H_4NO_2\text{-}p + p\text{-}CH_3C_6H_4SO_2NC_5H_{10}$$

$$p\text{-}C_7H_7SO_2(m\text{-}O_2NC_6H_4SO_2)NC_6H_4NO_2\text{-}m + C_5H_{10}NH \rightarrow$$

$$m\text{-}O_2NC_6H_4SO_2NHC_6H_4NO_2\text{-}m + p\text{-}C_7H_7SO_2NC_5H_{10}$$

Substitution Reactions of Sulfonamides. What little evidence there is indicates that simple sulfonamides and their N-alkyl derivatives substitute *meta* to the sulfur, the sulfonamide grouping showing a directive influence similar to that of the sulfonic acid and sulfonyl chloride groups. Attempts to introduce substituents into the nucleus of a sulfonamide are complicated by reaction of the amide group in practically all instances. The halogens and hypohalous acids give only N-substitution products except with a compound such as sulfanilamide (see p. 600), whereas sulfuric or chlorosulfonic acid produces cleavage to the sulfonic acid or acid chloride and an amine salt (see hydrolysis reactions). Benzenesulfonamide[117] and its N-alkyl derivatives[118] yield N-nitro compounds first, but with an excess of concentrated nitric acid it is possible to introduce a nitro group into the benzene ring.[119] Amides of *p*-toluenesulfonic acid[120] behave similarly while *p*-carboxybenzenesulfonmethylamide[121] nitrates only on the nitrogen. One might expect from this that sulfonamides of dialkylamines would substitute directly in the ring but benzenesulfondimethylamide yields dimethylnitroamine[118b] and the diethylamine derivative is converted into benzenesulfonethylnitroamide. Dibenzenesulfonpiperazide[122] reacts as shown in the equation. It has been reported[123] that *p*-toluenesulfonylglycine may be mono- and dinitrated without substitution on the nitrogen occurring. It is apparent that the presence of the carboxyl group reduces the reactivity of the imino hydrogen.

$$C_6H_5SO_2NHCH_3 \rightarrow C_6H_5SO_2N(NO_2)CH_3 \rightarrow$$

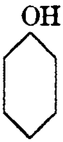
$$m\text{-}O_2NC_6H_4SO_2N(NO_2)CH_3$$

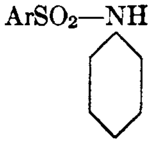
$$C_6H_5SO_2N(CH_2CH_2)_2NSO_2C_6H_5 + 2HNO_3 \rightarrow$$

$$O_2NN(CH_2CH_2)_2NNO_2 + 2C_6H_5SO_3H$$

Many investigations have been made of the substitution reactions of N-arylsulfonamides. Halogenation and nitration of the amine nucleus occur easily but sulfonating agents yield hydrolysis products in all reactions so far reported. Under proper experimental conditions such as the use of sulfur trioxide or chlorosulfonic acid in a solvent, sulfonic acids might possibly be prepared.

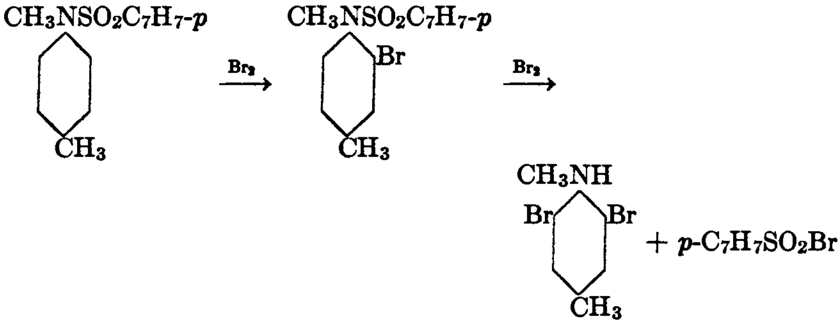
It is to be expected that the ease of substitution of an anilide would decrease with an increase in the strength of the acid from which the anilide is derived, and this has been suggested for the relative ease of chlorination of acetanilide and sulfonanilides.[124] This idea is not generally valid, however. A quantitative study of relative chlorination rates in 99% acetic acid at 20° of various anilides [125] showed that while benzenesulfonanilide chlorinated only two-thirds as fast as acetanilide and benzanilide, formanilide reacted much more slowly and gave a relative rate of 9.2 against 43 for benzenesulfonanilide. Jones [126] found that benzenesulfon-*o*-chloroanilide chlorinated about 60% as fast as the *p*-toluene-derivative. Brominations in pyridine and nitrations under various conditions occur more readily for sulfonanilides than for anilides of carboxylic acids. In these two substitutions the aromatic sulfonamido group has a directive influence quite comparable to that of phenolic hydroxyl. It is interesting to note that these two groups are similar in that in each the atom attached to the nucleus bears a weakly acidic hydrogen. Replacing the hydrogen by an alkyl decreases the ease of substitution in either type of compound.





The results obtained in the chlorination of a variety of sulfonanilides in ether or tetrachloroethane solution at ordinary temperatures [124] are shown in Table II. Substitution occurs only in the amine nucleus. Various sulfonamides of *p*-phenetidine do not yield homogeneous reaction products. It is to be noted in Table II that amides of nitrotoluenesulfonic acids are chlorinated less completely than amides not containing the nitro group.

An investigation of the bromination of toluenesulfonanilides [127] showed that mono and dibromo compounds could be prepared but further action of the halogen split the molecule to yield the toluenesulfonyl bromide and tribromoaniline. *Ortho* and *p*-toluidides monobrominate readily. The N-methyl derivative of the latter also brominates readily, the 2-bromo compound being readily split by excess bromine.

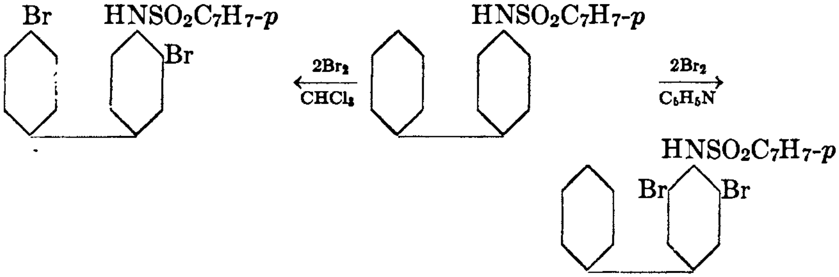


A comprehensive study of the bromination reactions of 4-(p-toluenesulfonamido)-biphenyl[128] and some nitro derivatives demonstrated that the position taken by the bromine atom was largely a function of the reaction medium. Thus in pyridine dibromination gives the 3,5-compound while in chloroform reaction occurs at the 3,4′-positions.

TABLE II

CHLORINATION OF SULFONANILIDES

Sulfonanilide	Chlorination Product	Yield, %	M.P. of Product, °C.
p-$C_7H_7SO_2NHC_6H_5$	2′,4′-dichloro	.....	....
4,3-$CH_3(O_2N)C_6H_3SO_2NHC_6H_5$	4′-chloro and other products	45	....
2,5-$CH_3(O_2N)C_6H_3SO_2NHC_6H_5$	4′-chloro	85	176
β-$C_{10}H_7SO_2NHC_6H_5$	4′-chloro	70	94
p-$C_7H_7SO_2NHC_6H_4CH_3$-2′	4′-chloro	90	143
4,3-$CH_3(O_2N)C_6H_3SO_2NHC_6H_4CH_3$-2′	4′-chloro	.....	139
o-$C_7H_7SO_2NHC_6H_4CH_3$-2′	4′-chloro	.....	154
2,5-$CH_3(O_2N)C_6H_3SO_2NHC_6H_4CH_3$-2′	No reaction (?)	.....	....
β-$C_{10}H_7SO_2NHC_6H_4CH_3$-2′	4′-chloro	.....	179
p-$C_7H_7SO_2NHC_6H_4CH_3$-4′	2′-chloro (5% excess Cl_2)	60–65	103
	2′,3′,5′-trichloro (excess Cl_2)	.....	176
4,3-$CH_3(O_2N)C_6H_3SO_2NHC_6H_4CH_3$-2′	4′-chloro	80	152
2,5-$CH_3(O_2N)C_6H_3SO_2NHC_6H_4CH_3$-4′	2′-chloro	75	154
β-$C_{10}H_7SO_2NHC_6H_4CH_3$-4′	Mixture	.....	....
p-$C_7H_7SO_2NHC_{10}H_7$-1′ p-$C_7H_7SO_2NHC_{10}H_6Cl$-1′,4′	2′,4′-dichloro	.....	188
4,3-$CH_3(O_2N)C_6H_3SO_2NHC_{10}H_7$-1′	Mixture	.....	....
2,5-$CH_3(O_2N)C_6H_3SO_2NHC_{10}H_7$-1′	4′-chloro	75	177
β-$C_{10}H_7SO_2NHC_{10}H_7$-1′	4′-chloro	.....	160
p-$C_7H_7SO_2NHC_{10}H_7$-2′	1′-chloro (SO_2Cl_2 as reagent)	87	112–114
[4-(p-$C_7H_7SO_2NH)C_6H_4]_2$	3,3′-dichloro	80	194
[4-(β-$C_{10}H_7SO_2NH)C_6H_4]_2$	3,3′-dichloro	70	237



The latter compound further brominates to the 3,5,4′-tribromo derivative. 3-Nitro and 3-bromo-4-*p*-toluenesulfonamidobiphenyl brominate in the 5-position in pyridine and in the 4′-position in acetic acid. 4-(*o*-Toluenesulfonamido)-biphenyl brominates analogously to the *para* isomer.

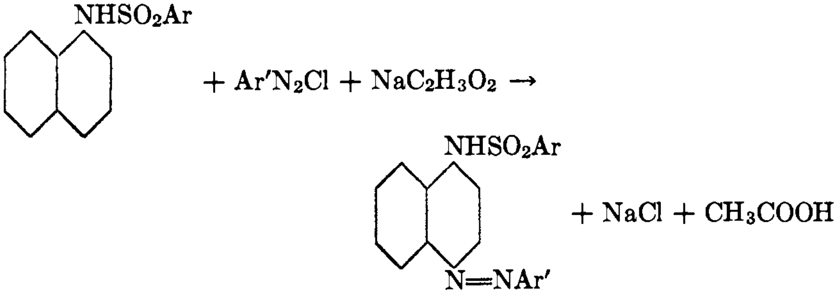
The behavior of a variety of N-arylsulfonamides toward nitration has been reported in the literature. The results of these investigations are summarized in Table III. In general the sulfonamido group possesses a stronger directive influence than does an ether linkage.

The process of preparing dinitroarylamines by nitration of sulfonanilides[129] and hydrolysis has been patented.

Nitration of sulfonamides with nitrogen tetroxide yields products similar to those listed in Table III. If the sulfonamide is derived from a secondary amine even excess of the oxide does not introduce more than one nitro group, however.[127]

Methanesulfonanilide nitrates similarly to the derivatives of aromatic sulfonic acids.[130]

The similarity in the directive influences of the phenolic and sulfonamide groups is again evident in the reaction of sulfonamides of aromatic amines with diazonium compounds in alkaline solution.[131] The resulting azo compounds may be converted into amines[132] without



loss of the amide group.

TABLE III

NITRATION OF SULFONANILIDES

Sulfonamide	Position(s) of Nitro Group(s)	M.P. of Nitro Comp., °C and Reference
Primary Amines		
p-$C_7H_7SO_2NHC_6H_5$	4′-	191^1
$C_6H_5SO_2NHC_6H_4Cl$-2′	4′-	161^1
$C_6H_5SO_2NHC_6H_4NO_2$-2′	4′,6′-di- (?)	$210–211^{17}$
$C_6H_5SO_2NHC_6H_4NO_2$-4′	2′,6′-di- (?)	$210–211^{17}$
p-$C_7H_7SO_2NHC_6H_4NO_2$-4′	2′-	161^8
p-$C_7H_7SO_2NHC_6H_4Cl$-2′	4′-	164^1
p-$C_7H_7SO_2NHC_6H_4Cl$-4′	2′-	110^4
p-$C_7H_7SO_2NHC_6H_4CH_3$-2′	4′-	$173–175^1$
m-$O_2NC_6H_4SO_2NHC_6H_4NO_2$-2′	4′-	210^8
p-$C_7H_7SO_2NHC_6H_4C_2H_5$-2′	4′-	107^1
p-$O_2NC_6H_4SO_2NHC_6H_4CH_3$-4′	2′,6′-di-	185^2
p-$C_7H_7SO_2NHC_6H_3(CH_3)Cl$-4′,2′	6′- (?)	197^3
p-$C_7H_7SO_2NHC_6H_3(CH_3)Cl$-2′,4′	6′-	145^3
2,5-$CH_3(O_2N)C_6H_3SO_2NHC_6H_5$	4′-	$?^3$
2,5-$CH_3(O_2N)C_6H_3SO_2NHC_6H_4CH_3$-4′	2′-	189^3
p-$C_7H_7SO_2NHC_6H_3(CH_3)_2$-2′,5′	4′-	185^1
$C_6H_5SO_2NHC_5H_4OCH_3$-2′	4′-	181^1
p-$C_7H_7SO_2NHC_6H_4OCH_3$-2′	4′-	$175^{1,\ 18}$
$C_6H_5SO_2NHC_6H_4OC_2H_5$-4′	2′-	72^4
p-$C_7H_7SO_2NHC_6H_4OC_2H_5$-4′	2′-	94^4
p-$C_7H_7SO_2NHC_6H_3(OC_2H_5)CH_3$-2′,5′	4′-	150^1
4,3-$CH_3(O_2N)C_6H_3SO_2NHC_6H_4OCH_3$-4′	2′-	135^9
	2′,3′-di-	$173–175^9$
	2′,5′-di-	152^9
	2′,6′-di-	147^9
	2′,3′,6′-tri-	$188–189^9$
4,3-$CH_3(O_2N)C_6H_3SO_2NHC_6H_4OC_2H_5$-4′	2′-	$135–136^{10}$
	2′,6′-di-	163^{10}
	2′,3′-di-	163^{10}
	2′,3′,6′-tri-	$233–234^{10}$
4-(p-$C_7H_7SO_2NH)C_6H_4C_6H_5$	3-	$\ldots^5$
	3,5-di-	189^2
4-(m-$O_2NC_6H_4SO_2NH)C_6H_4C_6H_6$	3-	170^6
	3,5-di-	199^6
2-(p-$C_7H_7SO_2NH)C_6H_4C_6H_5$	5-	169^2
	3,5-di-	186^2
2-(m-$O_2NC_6H_4SO_2NH)C_6H_4C_6H_6$	5-	150^6
	3,5-di-	148^6
	3,5,4′-tri-	$170–175^6$
3,4-Br(p-$C_7H_7SO_2NH)C_6H_3C_6H_5$	5-	191^7
4-(p-$C_7H_7SO_2NH)C_6H_4C_6H_4Br$-4′	3,5-di-	233^7
3,4-Br(p-$C_7H_7SO_2NH)C_6H_3C_6H_4Br$-4′	5-	229^7
3,4-Br(p-$C_7H_7SO_2NH)C_6H_3C_6H_4NO_2$-4′	5-	250^7

TABLE III (*Continued*)

Sulfonamide	Position(s) of Nitro Group(s)	M.P. of Nitro Comp., °C. and Reference
Primary Amines (Continued)		
2-(p-$C_7H_7SO_2NH$)$C_6H_4C_6H_4NO_2$-4′	3,5-di-	190[9]
[4-(p-$C_7H_7SO_2NH$)C_6H_4]$_2$	3,3′-di-	220[11]
1-($C_6H_5SO_2NH$)$C_{10}H_7$	2,4-di-	185–186[13]
2-($C_6H_5SO_2NH$)$C_{10}H_7$	1-	156[4, 12]
4,1-Br($C_6H_5SO_2NH$)$C_{10}H_6$	2-	. . .[12]
1-(p-$C_7H_7SO_2NH$)$C_{10}H_7$	2,4-di-	. . .[10]
2-(p-$C_7H_7SO_2NH$)$C_{10}H_7$	1-	160–161[13]
	1,6-di-	. . .[13]
2,6-(p-$C_7H_7SO_2NH$)$C_{10}H_6SO_3H$	1-	. . .[13]
Secondary Amines		
p-$C_7H_7SO_2N(CH_3)C_6H_5$	2′- and 4′-	126[11] and ?
p-$C_7H_7SO_2N(C_2H_5)C_6H_5$	4′-	107[1]
$C_6H_5SO_2N(CH_3)C_6H_4NO_2$-2′	4′,6′-di- (?)	181–182[13]
4-[p-$C_7H_7SO_2N(CH_3)$]$C_6H_4C_6H_5$	3-	157[11]
2-[$C_6H_5SO_2N(CH_3)$]$C_{10}H_7$	1-	158, 159[13]
2-[p-$C_7H_7SO_2N(CH_3)$]$C_{10}H_7$	1-	152–153[13]
	1,6-di-	180–181[13]
2-[p-$C_7H_7SO_2N(C_4H_9$-n)]$C_{10}H_7$	1-	129–130[14]
p-$C_7H_7SO_2N(C_6H_5)_2$	4′,4″-di-	167–168[13]

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[1] Akt.-Ges. für Anilinfabrik, German pat., 157,859, *Chem. Zentr.*, I, 415 (1905); German pat. 163,516, *ibid.*, II, 1207 (1905).

[2] Bell, *J. Chem. Soc.*, 2770 (1928).

[3] Schuloff, Pollak, and Riesz with co-workers, *Ber.*, **62B**, 1846 (1929).

[4] Akt.-Ges. für Anilinfabrik, German pat., 164,130; *Chem. Zentr.*, II, 1476 (1905).

[5] Bell and Kenyon, *J. Chem. Soc.*, 2705 (1926).

[6] Bell, *ibid.*, 1071 (1930).

[7] Bell, *ibid.*, 2338 (1931).

[8] Bell, *J. Chem. Soc.*, 2787 (1929).

[9] Reverdin, *Helv. Chim. Acta*, **7**, 567 (1924).

[10] Reverdin, *ibid.*, **8**, 602 (1925).

[11] Bell and Robinson, *J. Chem. Soc.*, 1127 (1927).

[12] Morgan and Godden, *ibid.*, **97**, 1711 (1910).

[13] Morgan and Micklethwait, *ibid.*, **101**, 143 (1912).

[14] Reilly, Drumm, and O'Sullivan, *J. Soc. Chem. Ind.*, **46**, 436 (1927).

[15] Reverdin and Crépieux, *Ber.*, **35**, 1442 (1902).

[16] Opolski, *Anz. Akad. Wiss. Krakau*, 26 (1910); *C.A.*, **5**, 1398 (1911).

[17] Opolski, *Ber.*, **40**, 3528 (1907).

[18] Mosby, Olpin, and Ellis, U. S. pat., 1,883,393, *C.A.*, **27**, 731 (1933).

[19] Hodgson and Walker, *J. Chem. Soc.*, 180 (1934).

Miscellaneous Reactions of Sulfonamides. Treating benzenesulfonamide with one mole equivalent of nitrous acid at 15° in aqueous solution [133] produces benzenesulfonic acid, dibenzenesulfonhydroxylamine, and benzenesulfonamide in about equal amounts. No further study of this reaction has been found. Benzenesulfonethylamide has been converted into the nitroso compound [134] which with potassium naphthoxide yields the ethyl ether.

$$C_6H_5SO_2N(NO)C_2H_5 + \beta\text{-}C_{10}H_7OK \rightarrow \beta\text{-}C_{10}H_7OC_2H_5 + ?$$

When treated with 100% nitric acid in sulfuric acid at 0° benzenesulfonamide gives the nitramide.[135] This is one of the strongest of the ammono acids, forming salts stable in water solution; most of these are soluble in liquid ammonia.[136]

$$C_6H_5SO_2NH_2 + HNO_3 \rightarrow C_6H_5SO_2NHNO_2 + H_2O$$

Heating a sulfonamide in solution with an aromatic mercury compound [137] results in mercuration of the amide group to give a compound claimed to be valuable as a germicide, insecticide, or fungicide.

$$C_6H_5SO_2NH_2+C_6H_5HgOOCH_3 \rightarrow C_6H_5SO_2NHHgC_6H_5+CH_3COOH$$

Sodium benzenesulfonmethylamide reacts with cyanogen bromide [138] to give the cyanamide. α-Naphthylcyanamide has been prepared from the sulfonyl chloride.[139] Upon heating the cyanamide to 150° in a vacuum decomposition into the amide and cyanuric acid takes place.

$$C_6H_5SO_2N(Na)CH_3 + BrCN \rightarrow C_6H_5SO_2N(CN)CH_3 + NaBr$$
$$C_{10}H_7SO_2Cl + NaNHCN \rightarrow C_{10}H_7SO_2NHCN + NaCl$$

As might be expected, fusion of sulfonamides with alkali gives results similar to those obtained with sulfonic acids. It has been mentioned earlier that certain sulfonamides may be hydrolyzed by heating with strong aqueous alkali. With potassium hydroxide and lead dioxide at 220° the toluenesulfonamides give a mixture of products.[140]

$$o\text{-}CH_3C_6H_4SO_2NH_2 \rightarrow o\text{-}CH_3C_6H_4OH + o\text{-}C_6H_4(OH)COOH + C_6H_5COOH$$

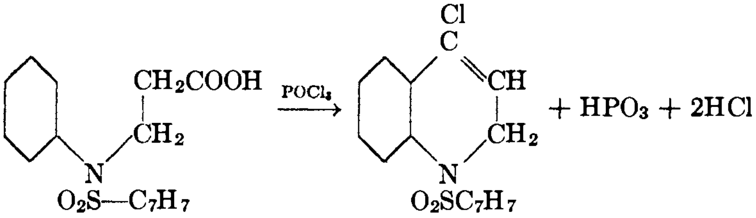
By working up the reaction mixture obtained from heating benzenesulfonamide with phosphorus pentachloride [141] there was obtained a phosphorus oxychloride derivative. *p*-Sulfamidobenzoic acid at a high temperature with the same reagent yields *p*-chlorobenzonitrile.[142] If the temperature is kept at 220° the intermediate *p*-cyanobenzenesulfonyl chloride results [143] while at a somewhat lower temperature [144] a phosphorus compound was isolated.

$$C_6H_5SO_2NH_2 \xrightarrow{PCl_5} C_6H_5SO_2NHPOCl_2$$

$$HOOCC_6H_4SO_2NH_2 + 2PCl_5 \rightarrow ClOCC_6H_4SO_2NPCl_3 + POCl_3 + 3HCl$$

Long heating of benzenesulfonanilide with phosphorus pentachloride [145] results in chlorination to give benzenesulfon-*p*-chloroanilide as the chief product.

Phosphorus oxychloride apparently has no effect upon the amide group but does bring about ring closure when it acts upon *p*-toluenesulfon-β-anilinopropionic acid[146] and similar compounds.

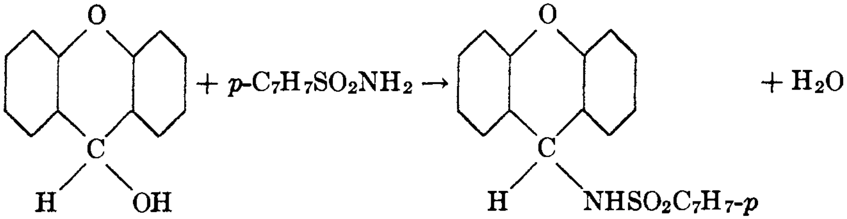


The sodium salt of *p*-toluenesulfonanilide and similar compounds react with sulfuryl chloride to give the N-chlorosulfonyl-*p*-toluenesulfonanilide.[147a, b] These compounds are similar in behavior to trichloromethanesulfonyl chloride; the chlorine hydrolyzes with difficulty, and the compounds show oxidizing properties. Titanium tetrachloride forms an addition compound with *p*-toluenesulfonamide[147c] but no further reaction was observed.

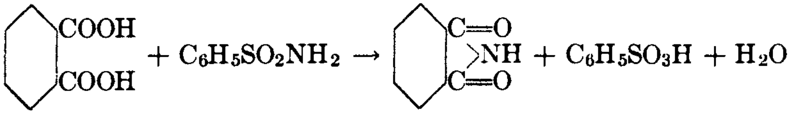
Phenyl isocyanate reacts with benzenesulfonamide as it does with most compounds containing an active hydrogen.[148] Benzenesulfonyl isocyanate reacts in similar fashion.[149] These urea derivatives have not been studied further.

$$C_6H_5SO_2NCO + C_6H_5SO_2NH_2 \rightarrow (C_6H_5SO_2NH)_2CO$$

It has been found[150] that heating *p*-toluenesulfonamide and other more complex amides in acetic acid with xanthhydrol produces a condensation product, probably as shown in the equation.



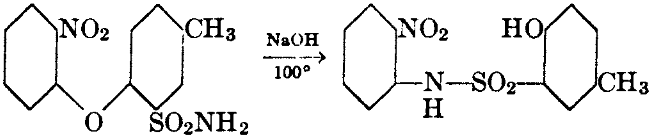
It has already been noted in the section on hydrolysis of sulfonamides that heating an amide with benzoic acid produces an amidine sulfonate as the principal product. This reaction was discovered as the result of the pyrolysis of compounds containing carboxy and sulfonamide groups in the same molecule.[81, 143, 144, 151] Heating *p*-carboxybenzenesulfonamide at 220° gives a mixture of at least four substances: *p*-carboxybenzenesulfonic acid, the ammonium salt of this acid, benzamidinesulfonic acid, and a substance with the same empirical formula as saccharin but whose formula is unknown. Benzamide and benzenesulfonamide do not react at 220° unless there is a molecular equivalent of benzenesulfonic acid present.[81] By treatment with phthalic acid benzenesulfonamide is converted practically quantitatively into the sulfonic acid. The *meta* and *para* acids yield the dinitriles in both cases. For the behavior of other acids the original should be consulted.



p-Toluenesulfondiphenylamide[152] gives no indication of reacting with phenylmagnesium bromide at room temperature. The ethyl esters of sulfonamidoacetic acid react with a Grignard reagent at the ester group.[153]

$$p\text{-}C_7H_7SO_2NHCH_2COOC_2H_5 \xrightarrow[H_2O]{C_6H_5MgBr} p\text{-}C_7H_7SO_2NHCH_2C(OH)(C_6H_5)_2$$

It has been shown that certain sulfonamides derived from aryl ethers where the ether linkage is activated by a nitro group undergo rearrangement in alkaline solution.[154] This is illustrated by the equation. The N-methylamide behaves similarly.



The oxidation of *p*-toluenesulfonamide to the carboxylic acid occurs in the body.[155] The benzenesulfonyl derivative of α-(N-methylamino)-lauric acid is oxidized down to the adipic acid derivative. Other oxidations of toluenesulfonamides are described in the section on saccharin.

SULFANILAMIDE AND RELATED COMPOUNDS

The general methods utilized in preparing sulfanilamide and its derivatives have been described in an earlier section. Here the chemical properties and methods for analysis of these compounds are given where they have any interest from the standpoint of sulfonamide chemistry. No attempt has been made to list the known compounds or to describe their pharmacological behavior as these items are thoroughly covered in other publications.[1]

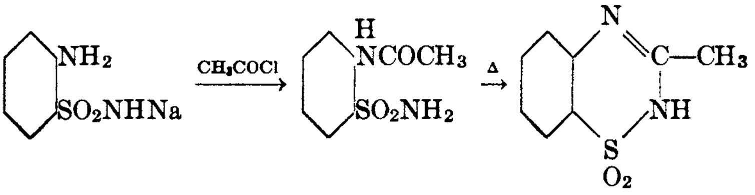
Reactions of Sulfanilamide. One of the interesting aspects of sulfanilamide chemistry is the difference in behavior of the two -NH_2 groups toward various reagents. While the ring nitrogen is slightly basic the amide group is acidic and the basic group is the one that reacts with most reagents. For example, when heated with ethyl oxalate the mono-anilide[156] results.

$$(COOC_2H_5)_2 + H_2NC_6H_4SO_2NH_2 \rightarrow C_2H_5OOCCONHC_6H_4SO_2NH_2 + C_2H_5OH$$

With any of the common acylating agents the amide group is likewise undisturbed.[157] Succinic and phthalic anhydrides[158] give the

$$RCOCl + H_2NC_6H_4SO_2NH_2 \rightarrow RCONHC_6H_4SO_2NH_2 + HCl$$

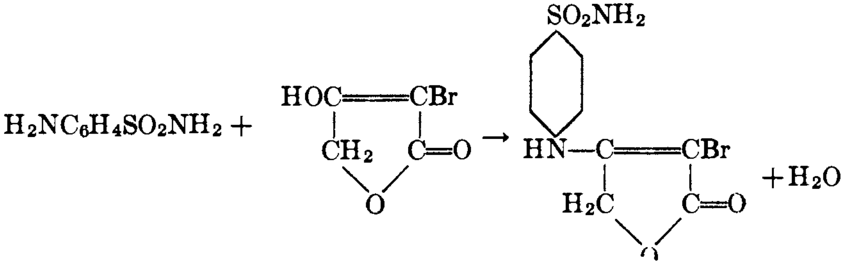
mono-anilides. In the case of the *o*-aminobenzenesulfonamide[159] acetylation of the amino group is possible but on heating the anilide to 200° or treating with acetic anhydride ring closure occurs.



Sulfanilamide reacts with an aldose such as *d*-glucose or *d*-mannose under a variety of conditions[160] to give comparatively non-toxic crystalline products, presumably with the formula shown.

$$C_6H_{11}O_5OH + H_2NC_6H_4SO_2NH_2 \rightarrow C_6H_{11}O_5NHC_6H_4SO_2NH_2 + H_2O$$

The enol form of α-bromotetronic acid also condenses.[161]



Nitrosobenzene reacts with the basic amino group to give the azo compound.[162] Oxidation[163] of sulfanilamide gives either the azo- or azoxybenzenedisulfonamide except that hydrogen peroxide and hydrochloric acid give the dichlorosulfanilamide. Oxidation in the body forms a number of products;[164] glucuronates of *p*-aminophenol and *p*-(N-acethydroxylamino)-benzenesulfonamide, *p*-hydroxylaminobenzenesulfonamide, and pigments derived from the aminophenol have been reported. With hydrogen peroxide in the presence of iron substantially the same products are obtained as in the body.[165]

The irradiation of an aqueous solution of sulfanilamide results in the formation of ammonia and also some sulfur appears as sulfate ion. This behavior is not shared by the *ortho* and *meta* isomers and by the N^4-acetyl derivative.[166]

It has been mentioned that sulfanilamide can be chlorinated in the nucleus. With iodine monochloride[167] mono- and diiodo compounds are produced. The action of an acid upon the monoiodination product partially converts it into the diiodo compound. Iodine in sodium bicarbonate brings about oxidation to the azobenzenedisulfonamide. The action of potassium permanganate upon the diiodosulfanilamide yields the nitroso compound.

Sulfanilamide can be diazotized normally and converted into the phenol in about 65% yield.[168a] Antimony derivatives[168b] have also been made from the diazonium salt. The 3-nitrosulfanilamide prepared through nitration of N^4-acetylsulfanilamide, followed by hydrolysis, reacts with alkali with evolution of ammonia to give the phenolsulfonamide.

Analytical Determination of Sulfanilamide. A variety of analytical procedures for the estimation of sulfanilamide have been developed because of the importance of being able to determine the purity of any sample of it used as a drug and because of the interest in its fate after introduction into the organism. On a micro-scale sulfanilamide gives characteristic products with iodine monochloride, formaldehyde, picric acid, and mercury salts.[169] The appearance of sulfanilamide crystals under the polarizing microscope has been described.[170] The purity of a sample may be found by determining its crystallizing point[171] or by analysis by one of the procedures useful for sulfanilamide solutions. The titration of sulfanilamide with standard bromate-bromide solution, followed by addition of potassium iodide and back-titration with thiosulfate gives results that are consistently a little high.[172] Hydrolysis by refluxing for 30 minutes with 75% sulfuric acid followed by adding alkali and by distilling and titrating the ammonia works satisfactorily.

All the procedures most frequently employed for determining quantitatively the minute amounts of sulfanilamide in body fluids involve the formation of highly colored compounds. The color produced is then compared with that obtained from a known amount of the amide under the same conditions. Marshall[173] found that diazotization and coupling with dimethyl-α-naphthylamine worked well. For this amine there have been substituted diphenylamine,[174] N-α-naphthylethylenediamine,[175] α-naphthol,[176] and chromatropic acid,[177] and undoubtedly other amines and phenols would serve. Many practical applications of Marshall's method and its modifications have been described.[178] A second type of colorimetric method involves a condensation reaction of an aldehyde or quinone with the amino group of sulfanilamide. Schmidt[179] has made use of β-naphthoquinone-4-sulfonate. Other investigators[180] have employed cinnamic aldehyde and *p*-dimethylaminobenzaldehyde.[181] Benzaldehyde and cinnamic aldehyde have also been used in microscopic identification procedures.[182] Condensing an acridinealdehyde[183] with sulfanilamide at 150° gives a yellow anil, but apparently it was not used for analytical purposes.

Other observations of possible value in analytical procedures include the fact that *p*-cresoltyrosinease[184] gives a red color with a number of sulfanilamide drugs, including compounds in which the amino group is altered;[185] hydrogen peroxide gives a blue-violet derivative unstable in water but stable in *n*-butyl alcohol;[186] and with copper sulfate,[187] complex ions are formed.

Some information is available on analytical methods for other drugs of the sulfanilamide series.[188] The acyl group of N^4-acylsulfanilamide derivatives hydrolyzes readily even at 37.5° with dilute hydrochloric acid.[189] Such compounds can therefore be determined quantitatively by the methods used for sulfanilamide provided a preliminary hydrolysis is carried out.

Two methods for distinguishing between sulfanilic acid and sulfanilamide have been mentioned.[190] Upon heating, the former carbonizes whereas the latter gives an intense violet color. Sulfanilamide also gives characteristic needles with bromine in aqueous potassium bromide.[190]

The potentials existing in a solution where sulfanilamide is being oxidized with cerric sulfate[191] have been measured but the results apparently have not been applied to analytical procedures. Of some interest to the analyst is the report[192] on the solubility of sulfanilamide in mixtures of water and ethylene, propylene, or diethylene glycol. The last mentioned is by far the best solvent.

SOME N-SUBSTITUTED DERIVATIVES OF SULFONAMIDES

HALOGEN DERIVATIVES

The Action of Halogens and Hypohalites upon Sulfonamides. The action of a hypohalous acid or a hypohalite upon an aromatic sulfonamide in water solution replaces the amide hydrogen by halogen. In alkaline solution only one hydrogen is replaced and the alkali salt of the chloroamide results. Thus when *p*-toluenesulfonamide is dissolved in 1.3 to 2.0 *N* sodium hypochlorite containing one equivalent of sodium hydroxide,[1] part of the sodium salt crystallizes directly as the trihydrate and the remainder may be obtained by evaporating the solution. This compound is known commercially as Chloramine T.

$$p\text{-}C_7H_7SO_2NH_2 + NaClO \rightarrow p\text{-}C_7H_7SO_2NHCl + NaOH$$

$$p\text{-}C_7H_7SO_2NHCl + NaOH \rightarrow p\text{-}C_7H_7SO_2NClNa + H_2O$$

It is not necessary to have the excess alkali present since with 1.2 equivalents of hypochlorite followed by the addition of saturated sodium chloride solution[2] a 90% yield of the sodium salt separates. This contains some sodium chloride, readily removed by crystallizing the product from twice its weight of hot water.

A process described in the patent literature[3] involves the reaction of the sulfonamide with calcium hypochlorite and the addition of other inorganic salts to take up the water after the reaction.

An 85% yield of potassium *p*-toluenesulfonbromoamide separates when a mixture of 10 g. of *p*-toluenesulfonamide, 40 ml. of water, and 4 ml. of bromine is treated with 15 ml. of 50% alkali solution.[4] Similarly the alkali salts of sulfoniodoamides are conveniently obtained when concentrated sodium or potassium hydroxide is added to a mixture of the sulfonamide and iodine in the alkali iodide solution.[5]

Although the monochloroamides have been obtained pure only as their salts, in the preparation of *p*-carboxybenzenesulfondichloroamide (Halazone) by commercial methods a mixture of the mono- and dichloroamides results.[6] In these procedures the amide is acted upon by sodium hypochlorite or hypochlorous acid in basic solution, and then the solution is acidified. The higher the concentration of acid in the resulting solution the more monochloroamide is present in the precipitate. However, the dichloroamide still predominated under any conditions investigated.

The amides of aliphatic sulfonic acids do not appear to react with hypochlorites;[7] at least the N-chloro compounds could not be isolated.

ω-Toluenesulfonamide is an exception[8] although γ-phenylpropane-, cyclohexane-, and 1,2-ethanedisulfonic acids do not react.

The action of a halogen upon an aromatic sulfonamide in neutral or slightly acidic solution leads to the substitution of both hydrogens by halogen. Thus Kastle[9] first observed that passing chlorine into a solution of sodium benzenesulfonamide gives the dichloroamide.

$$C_6H_5SO_2NHNa + 2Cl_2 \rightarrow C_6H_5SO_2NCl_2 + NaCl + HCl$$

A more convenient procedure consists in dissolving the amide in bleaching powder solution and acidifying with acetic acid.[10] Carbon dioxide under pressure[11] is also suitable as an acidifying agent. Another convenient method[12] consists in dissolving the amide in aqueous sodium acetate and saturating the solution with chlorine. An adaptation of the original method of Kastle[9] has been used in large-scale production.[13a]

The preparations of the chloro and dichloroamides of azobenzenesulfonic acids have been described.[13b]

N-Alkyl- and N-arylsulfonamides react with one molecular equivalent of hypochlorous acid. To prevent nuclear substitution in the case of the aryl compounds it is necessary to keep the solution at the neutral point,[14a] rearrangement of halogen occurring under a variety of conditions.[14b]

$$ArSO_2NHR + HOCl \rightarrow ArSO_2NClR + H_2O$$

The sulfondibromoamides[9b,15] are easily[10] obtained by shaking the sulfonamide with hypobromous acid solution prepared from bromine water and mercuric oxide. The yields are quantitative.

Properties and Reactions of the Sulfonhaloamides. Because of their ease of preparation and stability, and their oxidizing and halogenating action[16] the sulfonchloroamides have proved to be both useful and interesting chemically. Several of them have been or are commercial products sold under various trade names. Of these sodium *p*-toluenesulfonchloroamide (Chloramine T, Chloramine, Activine, Chlorazene, Gansil, Mianine, Tochlorine, Tolamine, etc.) is the most prominent, chiefly because *p*-toluenesulfonamide is a by-product in the manufacture of saccharin and hence readily available. The dichloro derivatives of *p*-toluenesulfonamide (Dichloramine T) and p-carboxybenzenesulfonamide (Halazone), and sodium *o*-toluenesulfonchloroamide (Chloramine TO) also are obtainable from this source. Sodium benzenesulfonchloroamide (Chloramine B) has been much less studied.

Replacement of the amide hydrogens of *p*-toluenesulfonamide and its N-methyl derivative with chlorine eliminates the association in solution characteristic of the amides.[17a]

Many observations upon the stability of the haloamides have been reported.[17b] An aqueous solution of Chloramine T is stable in the dark [18] or diffused light but in sunlight [19a] the solution becomes acidic due to the formation of chlorosulfonic acids. A number of dyes act as desensitizers [19b] for the reaction in methanol solution. Halazone stored in the dry state for one year showed little deterioration [17b, 20] at ordinary temperatures but at 40–50° the efficiency of tablets containing this decreased 50% in three months.[21] Dichloramine T when in pure crystalline form is stable for eight months or more [20] in the absence of moisture and light. There is disagreement [22] as to its stability in Chlorcosane, a chlorinated paraffin oil, perhaps because of variability of different samples of paraffin utilized. A chlorobenzene solution keeps well [23a] as does a 5% solution in chlorophenyl phenyl ether.[23b]

Compounds of the sulfondihaloamide type melt without decomposition although when heated with a direct flame they explode. The tetrachloro compound derived from *m*-benzenedisulfonamide detonates under this treatment in a manner reminiscent of nitrogen trichloride,[10] while sulfonalkylchloroamides decompose rapidly but not explosively. The bright yellow dibromoamides decompose slowly at ordinary temperatures with evolution of bromine.[24a] In sulfuric acid at 20° benzenesulfondibromoamide [24b] rapidly changes to a dibromobenzenesulfonamide. Ring closure occurs when *p*-toluenesulfon-*n*-butylchloroamide is heated in aqueous sulfuric acid solution with formation of the pyrollidine sulfonamide in a 50% yield.[24c]

p-Toluenesulfondichloroamide hydrolyzes in water to hypochlorous acid and the monochloroamide.[25] The equilibrium constant for this reaction is 8.0×10^{-7} and that for the hydrolysis of the monochloro-

$$p\text{-}C_7H_7SO_2NCl_2 + H_2O \rightleftharpoons p\text{-}C_7H_7SO_2NHCl + HClO$$

amide is 4.9×10^{-8}. The hypochlorous acid content of an acid solution of the dichloramide is practically independent of the amount of the amide present. The rate of formation of hypochlorous acid from the monochloroamide as measured by the rate at which reaction with *p*-cresol occurs amounts to a 50% hydrolysis in 7 minutes at 25°. This is in contrast to N-chloroacetanilide which requires seven days for an equal change to occur. Since *p*-toluenesulfonamide reacts with N-chloroacetanilide directly to give *p*-toluenesulfonchloroamide, *p*-toluenesulfonamide is a good catalyst for the hydrolysis of N-chloroacetanilide.

When a sulfondichloroamide is treated with alkali it dissolves and there crystallizes from the solution the salt of the monochloro compound.[26] In the presence of a mole of unsubstituted amide two moles of the alkali salt are produced.

$$p\text{-}C_7H_7SO_2NCl_2 + 2KOH \rightarrow p\text{-}C_7H_7SO_2NClK + KOCl + H_2O$$

$$p\text{-}C_7H_7SO_2NCl_2 + p\text{-}C_7H_7SO_2NH_2 + 2KOH \rightarrow 2p\text{-}C_7H_7SO_2NClK + 2H_2O$$

If a solution of the salt is acidified the original dichloroamide is regenerated.

$$2p\text{-}C_7H_7SO_2NClK + 2CH_3COOH \rightarrow p\text{-}C_7H_7SO_2NCl_2 + C_7H_7SO_2NH_2 + 2CH_3COOK$$

The dichloroamides react readily with the common reducing agents. With hydrochloric acid free chlorine is generated and with hydrogen iodide the product is iodine or iodine chloride depending upon the ratio of the reactants.[10]

$$C_6H_5SO_2NCl_2 + 2HI \rightarrow C_6H_5SO_2NH_2 + 2ICl$$

Sulfur is liberated from hydrogen sulfide and with hydrogen cyanide cyanogen chloride is formed. With ethanol ethyl hypochlorite is the primary product but this readily decomposes.

$$C_6H_5SO_2NCl_2 + 2C_2H_5OH \rightarrow C_6H_5SO_2NH_2 + 2C_2H_5OCl$$

$$C_2H_5OCl \rightarrow CH_3CHO + HCl$$

The dibromoamides show a similar behavior.

Dichloramine T oxidizes hydrazobenzene to azobenzene in chloroform solution.[27a] When an attempt was made to use Dichloramine T as a "nitridizing agent" in liquid ammonia it was found that reaction with ammonia occurred at once.

$$3C_7H_7SO_2NCl_2 + 10NH_3 \rightarrow 3C_7H_7SO_2NH_2 + 2N_2 + 6NH_4Cl$$

When acetanilide and Dichloramine T are kept in chloroform at 20° for 5 hours a 95% yield of chlorinated acetanilides results of which 68% is the *p*-chloroacetanilide.[27b] Similar results were obtained in other solvents.

Since an aqueous solution of Chloramine T oxidizes a variety of inorganic and organic reducing agents this has been recommended for use in numerous analytical procedures. A 5% solution may be employed as a substitute for chlorine water[28] in detecting bromide and iodide ion, as a substitute for bleaching powder in the indophenol reaction, to replace hydrogen peroxide in the caffeine test and as the oxidizing agent in the indican test in urine. In quantitative analysis it is satisfactory for determining potentiometrically[29] trivalent bismuth and arsenic, bivalent tin and iron, ferrocyanide, sulfite, nitrite, and iodide ions, hydroquinone, quinhydrone, and hydrazine hydrochloride. A solution may be standardized against arsenic trioxide and does not change appreciably in three months. The titrations are carried out in acid solution. Thiocyanate ion[30] is oxidized quantitatively to cyanate and sulfate; hypophosphite to phosphite (24 hours' standing); and nitrous acid to nitric acid.[31] Of particular value is its substitution for iodine solutions in determining sulfite[32] in control tests in sulfite paper mills. The strength of sodium hydrosulfite solutions may also be determined.[33a] In fact, since iodide ion is readily oxidized to free iodine by the Chloramine T in acid solution the latter can be employed in any iodine titration by first adding a little potassium iodide and starch to the solution.[29b, 30, 33b]

The kinetics of the reaction between hydrogen peroxide and an acid solution of Chloramine T have been investigated[34] and found to be more complex than the stoichiometric reaction would indicate. The results obtained are best explained by the sequence of changes shown, the solution containing chlorine and hypochlorous acid in equilibrium amounts. The reaction between chlorine and hydrogen peroxide has

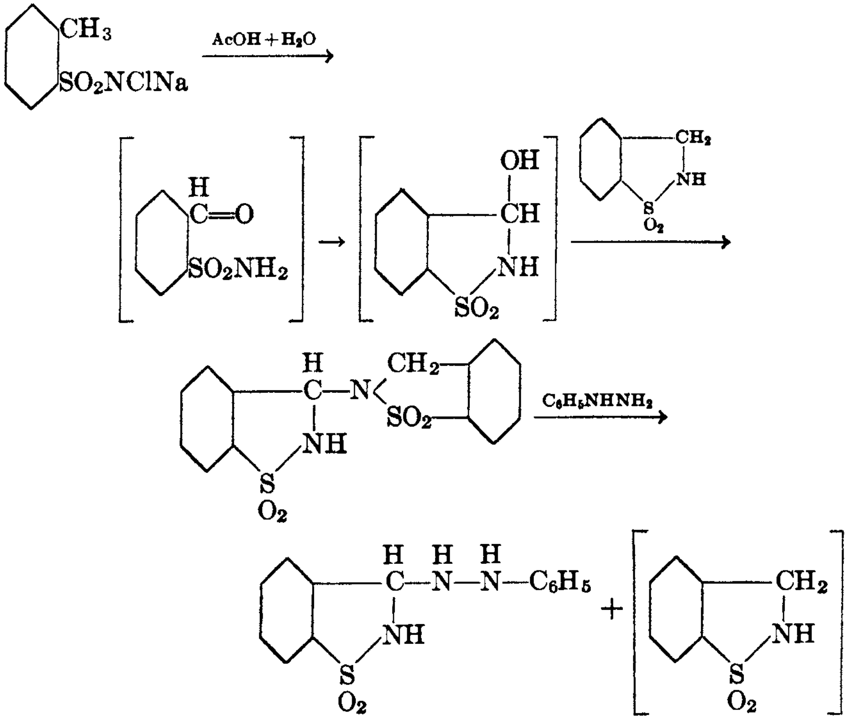
$$\begin{aligned} p\text{-}C_7H_7SO_2NCl^- + H^+ &\rightarrow p\text{-}C_7H_7SO_2NHCl \\ p\text{-}C_7H_7SO_2NHCl + H_2O &\rightleftharpoons p\text{-}C_7H_7SO_2NH_2 + HOCl \\ p\text{-}C_7H_7SO_2NHCl + H^+ + Cl^- &\rightleftharpoons p\text{-}C_7H_7SO_2NH_2 + Cl_2 \\ H_2O_2 + Cl_2 &\rightarrow 2H^+ + 2Cl^- + O_2 \end{aligned}$$

been investigated in some detail.[35]

A solution of Chloramine T or the corresponding bromine or iodine compound when added to a solution containing phenol and potassium iodide precipitates triiodophenol quantitatively.[4, 36] The reaction is not so satisfactory with 1- and 2-naphthol or resorcinol although under well-defined conditions a 47% yield of triiodoresorcinol has been obtained. *o*-Nitrophenol may be mono- or diiodinated depending upon the amount of reagent used. Amines are readily iodinated in glacial acetic acid,[37] aniline going to triiodoaniline. A number of polyhydroxyphenols which cannot be titrated give characteristic color reactions[38] with either Chloramine T or Halazone.

It has been claimed that a Chloramine T or Halazone solution may be employed in determining Hübl iodine numbers of fats and oils.[39] Likewise it has been mentioned that the detection of acetone or ethyl alcohol by conversion to iodoform is possible in solutions containing one part in ten thousand of either of these substances if Chloramine T is added to the solution along with iodine.[28b,36] Further information upon the advantages, if any, of these procedures seems desirable.

In acid solution sulfonchloroamides oxidize a methyl attached to the benzene ring to the aldehyde group, occasionally in good yields. Dakin[40] observed that when Chloramine T was heated with 5% glucose solution on the steam bath *p*-sulfamidobenzaldehyde could be extracted from the reaction mixture, the glucose being little affected. The aldehyde also is formed when an acidified Chloramine T solution is heated.[41] Similar treatment of the *ortho* isomer may give the aldehyde as an intermediate product but this undergoes ring closure and condensation reactions.



Phenylhydrazine converts the condensation product into what may be considered to be the phenylhydrazone of the cyclic form of the aldehyde, a derivative of dihydrobenzisothiazole.

To investigate the oxidizing action of a sulfonchloroamide upon other compounds containing a methyl group sodium benzenechloroamide and Halazone were chosen.[42] With toluene, *m*- and *p*-xylene, and *o*-nitrotoluene low yields (5–27%) of the aldehydes resulted when the oxidation was effected in dilute acetic acid solution with sodium benzenesulfonchloroamide. 2-Nitrotoluene-4-sulfonamide was more readily oxidized, 33 g. of aldehyde resulting from the oxidation of 45 g. of the sulfonamide with 28 g. of the benzenesulfonchloroamide by refluxing in 900 ml. of water and 6 ml. of acetic acid for 32 hours. 4-Nitrotoluene-2-sulfonamide gave the cyclic form of the aldehyde in smaller amount. Halazone *in alkaline solution* gave results much like these. Some 15 to 25% of the corresponding aldehyde was obtained from *o*- and *p*-toluenesulfonamide, the 2,4-disulfonamide, and the two nitrotoluenesulfonamides mentioned previously.

The decomposition of α-amino acids brought about by heating with Chloramine T is interesting because of the relation this may have to this compound's germicidal action.[2,40] *p*-Toluenesulfonamide is precipitated and the acid is converted to an aldehyde with one less carbon. Tryptophane is an exception giving a violet-colored substance of unknown nature, and asparagine undergoes further oxidation to the ketoaldehyde, isolated as the osazone. Glutamic acid, however, behaves normally giving β-aldehydopropionic acid in 0.1 *N*

$$H_2NOCCH_2CHNH_2COOH \rightarrow H_2NCOCOCHO$$

sodium hydroxide at 20°. In 0.2 *N* alkali at 35° β-cyanopropionic acid is obtained. No satisfactory reaction mechanism seems to have been developed to explain the products obtained in these transformations.

A reaction first reported by Nicolet and Willard[43] has been the basis of several investigations. When ethyl sulfide is heated with Chloramine T in alcohol, sodium chloride is precipitated and a new sulfur-nitrogen bond established. Hydrolysis of the product yields ethyl sulfoxide and *p*-toluenesulfonamide. This is a general reaction

$$C_7H_7SO_2NClNa + (C_2H_5)S \rightarrow C_7H_7SO_2NS(C_2H_5)_2 + NaCl$$

of sulfides;[44] the products from unsymmetrical sulfides, like the sulfoxides, exist in optically active forms and hence the sulfur-nitrogen bond is of the semi-polar type.

Bis- (β-chloroethyl) disulfide has been found to undergo cleavage at the sulfur-sulfur bond[45] to give a nitrogen analog of a sulfinic acid as one product. Tertiary amines do not react with sulfonchloroam-

$$(ClCH_2CH_2S)_2 + 2C_7H_7SO_2NClNa \rightarrow ClCH_2CH_2S(NSO_2C_7H_7)_2Na + ?$$

ides but other trisubstituted hydrides of the elements of this periodic group do. Triethyl-, triphenyl-, and the tritolylphosphines[46] in anhydrous alcohol give the simple coupling product but in 95% alcohol one or more other compounds are formed. The product obtained from

$$R_3P + C_7H_7SO_2NClNa \rightarrow R_3PNSO_2C_7H_7 + NaCl$$

triphenylphosphine also results when triphenylphosphine oxide and *p*-toluenesulfonamide are heated together in benzene solution. The trisubstituted arsines apparently do not yield the simple coupling

$$2(C_6H_5)_3P + 2C_7H_7SO_2NClNa + C_7H_7SO_2NH_2 \rightarrow [(C_6H_5)_3PNHSO_2C_7H_7]_2NSO_2C_7H_7 + 2NaCl$$

$$(m\text{-}C_7H_7)_3P + p\text{-}C_7H_7SO_2NClNa + H_2O \rightarrow (m\text{-}C_7H_7)_3P(OH)NHSO_2C_7H_7\text{-}p + NaCl$$

product, $R_3AsNSO_2C_7H_7$, but are converted into substances analogous to those obtained with phosphines in the presence of water, or at least only such compounds could be isolated.[47] Diaryl tellurides resemble arsines rather than sulfides. Arsinic acids may be obtained by the action of Chloramine T on chloroarsines.[48]

The reaction of Chloramine T or the dichloroamide with phenylmagnesium bromide is similar to that of nitrogen trichloride[49] in that chlorobenzene is formed in both reactions. Methoxyethylmercuric chloride with Chloramine T gives an N-Hg compound which is claimed[50] to have valuable germicidal properties. Presumably the reaction proceeds as follows.

$$CH_3OC_2H_4HgCl + C_7H_7SO_2NClNa \rightarrow C_7H_7SO_2N(HgC_2H_4OCH_3)Cl + NaCl$$

The behavior of the N-halosulfonamides toward olefins is apparently unique among haloamine derivatives.[51a,b] Benzenesulfonmethylbromoamide[51a] reacts with propenylbenzene to give the two stereoisomers having the bromine adjacent to the ring. One of these was also prepared by the action of phosphorus pentabromide upon the benzene-

$$C_6H_5CH{=}CHCH_3 + C_6H_5SO_2NBrCH_3 \rightarrow C_6H_5CHBrCH(NCH_3SO_2C_6H_5)CH_3$$

sulfonamide of *dl* ephedrine. With Chloramine T propenylbenzene gave only a 15% yield of the expected addition product. The reaction of cinnamyl alcohol with the bromoamide proceeded through a disproportionation.

$$2C_6H_5CH{=}CHCH_2OH + 2C_6H_5SO_2NBrCH_3 \rightarrow C_6H_5CHBrCHBrCH_2OH + C_6H_5SO_2N(CH_3)CH(C_6H_5)CH(CH_2OH)N(CH_3)SO_2C_6H_5$$

Allyl bromide appeared to give similar products although identification was incomplete.

Styrene[51b] reacts with benzenesulfonmethylbromoamide in the same manner as does propenylbenzene. The structure of the product was determined by removal of hydrogen bromide, reduction, and hydrolysis to give β-phenethylmethylamine and also by reduction with sodium and amyl alcohol.

$$C_6H_5CHBrCH_2N(CH_3)SO_2C_6H_5 \xrightarrow[ROH]{Na} C_6H_5CH_2CH_2NHCH_3 + C_6H_5SO_2Na + NaBr$$

Kharasch and Priestley[51b] demonstrated that the addition was general for alkylbromosulfonamides since N-bromo-*p*-toluenesulfonyl and ω-toluenesulfonyl derivatives of benzyl and phenethylamine gave the same reaction as the bromomethylamide. Further, they were able to substitute propylene, 2-methylpropene, and vinyl chloride for the styrene or propenylbenzene and still have reaction occur.

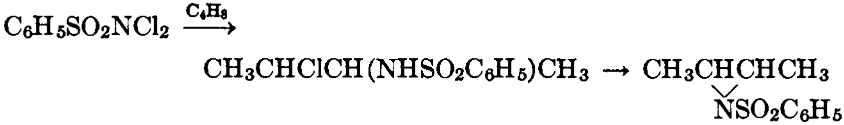
The reaction of *p*-toluenesulfondibromoamide[51b] with styrene is particularly interesting because the positions taken by the bromine and nitrogen are reversed when compared with the product from the methylbromoamide.

$$2C_6H_5CH{=}CH_2 + C_6H_5SO_2NBr_2 \rightarrow C_6H_5CH(NHSO_2C_6H_5)CH_2Br + C_6H_5C_2H_2Br$$

The action of alkali on the addition compound gave N-*p*-toluenesulfonylstyrene imine. Various reagents cleaved this to give β-phenethylamine derivatives, proving its structure. The benzyl carbon-nitrogen bond is always the point of attack in these reactions.

Indene[51c] reacts with *p*-toluenesulfondibromoamide in the same manner as does styrene and the addition product undergoes similar transformations.

The reaction of a dihaloamide with an olefin in a solvent such as a phenol, alcohol, or fatty acid produces a mixture of products apparently because of partial solvolysis of the amide. For example, the addition of benzenesulfondichloroamide to a mixture of phenol and 2-butene at −15° gives besides some chlorophenols about a 50% yield of 2-chloro-3-phenoxybutane and two stereoisomeric benzenesulfonchlorobutylamides.[52] These lose hydrogen chloride to give the *cis* and *trans* derivatives of the butylene imine. Similar experiments using



$$C_6H_5SO_2NCl_2 \xrightarrow{C_4H_8} CH_3CHClCH(NHSO_2C_6H_5)CH_3 \rightarrow CH_3\underset{NSO_2C_6H_5}{\underbrace{CHCH}}CH_3$$

1-butene give, besides a phenoxychlorobutane, a chlorobutylamide and the imine derivative as before, whereas isobutylene reacts mostly by substitution giving methallyl chloride and higher boiling products.

A solution of one of the butylenes in five to ten moles of a primary alcohol when treated with benzenesulfondichloroamide[53] gives as high as a 95% yield of the β-chlorobutyl alkyl ether. With less of the alcohol the formation of the β-chlorobutylsulfonamides becomes important. The percentage of butylene chloride formed is small, particularly at low temperatures ($-20°$).

Ethylene chlorohydrin and ethylene glycol give results analogous to those obtained with the simple alcohols.[54a]

The addition of benzenesulfondibromoamide to an alcohol solution of 1,3-butadiene[54b] produces a 3-alkoxy-4-bromo-1-butene in 50–70% yields.

If a dichloroamide is added to a mixture of a fatty acid and an olefin in ether the reactions that occur are analogous to those taking place between alcohols, olefins, and the amide,[55] chloro esters being formed.

$$C_6H_5SO_2NCl_2 + RCOOH \rightleftharpoons C_6H_5SO_2NHCl + RCOOCl$$

$$RCOOCl + R'CH{=}CHR'' \rightarrow R'CHClCH(OOCR)R''$$

The yields of esters are somewhat lower (27–40%) than of the ethers. Better results were reported when benzenesulfondibromoamide was used.

Germicidal and Physiological Properties of Sulfonhaloamides. In 1916 Dakin and co-workers[2] reported on a comprehensive investigation of the bactericidal properties of thirty-nine sulfonchloroamides, three bromoamides, and some chlorinated proteins in water and in horse serum. Some of the sodium sulfonchloroamides were found to have greater effectiveness on a molar basis than does sodium hypochlorite. The presence of a halogen, a nitro group or an alkyl group in the aromatic nucleus reduces the effectiveness slightly. The sulfonbromoamides are slightly inferior to the chloro compounds. Considering both effectiveness and cheapness sodium *p*-toluenesulfonchloroamide was chosen as most suitable for practical use,[56a, b] particularly in the treatment of wounds. A paste of sodium stearate containing not over 1.5% of the Chloramine T was found to be highly satisfactory for keeping wounds sterile.[56c] The chief advantages in the use of Chloramine T over sodium hypochlorite solution are its lack of irritant action[57] and the stability of its aqueous solutions which has already been remarked upon. Subsequently the value of the sulfonchloroamides as general disinfectants received much attention. Chloramine T[58a] and particularly Halazone (*p*-dichlörosulfonamidobenzoic acid)[58b] were found useful in sterilizing small amounts of drinking water. The taste of the water is not affected and the sulfonamide liberated is non-toxic when taken orally.[58c] Since on the basis of available chlorine ordinary chlorinated lime is twice as effective and cheaper than Halazone, the latter's stability in tablet form is its chief advantage.

Chloramine T exhibits a selective action toward various microörganisms. It is effective toward *Staph. aureus* and *B. coli*[59] in 2% and 0.5% solutions respectively but much less so against *B. pyocyaneus*. From 12 to 64 hours' exposure to a 1% solution was found necessary to kill anerobic spore-formers,[60] the activity here being actually less than that of phenol. In the presence of blood serum the effectiveness of Chloramine T drops to about 10% of the value in aqueous solutions.[61] The germicidal value depends greatly upon the *p*H of the solution and upon the temperature.[62] For a comparison or review of various commercial chlorinated bactericides[63] and for other miscellaneous applications of Chloramine T as a disinfectant[64] the voluminous original literature should be consulted.

Although it shows little toxicity when taken orally in moderate amounts, Chloramine T is highly toxic when injected intravenously,[65] depressing the central nervous system and producing pulmonary edema. When an attempt was made to treat pneumonia in dogs with a 1 to 10,000 solution they became worse and in well dogs a "sterile pneumonia" was produced.[66]

At about the same time that Dakin and co-workers investigated the usefulness of Chloramine T in aqueous solution in the treatment of wounds they also found that *p*-toluenesulfondichloroamide, Dichloramine T, in eucalyptol or Chlorcosane, a chlorinated paraffin oil,[67] possessed advantages over the aqueous hypochlorite solution then in use. The germicidal effect persisted for 18 to 24 hours and the solution dissolved dead tissue but was not destructive to live tissue as is iodine. Chlorcosane dissolved enough of the dichloroamide to produce an 8.5 to 10% solution which was comparatively stable. Aside from several discussions of the value of Dichloramine T solutions in wound treatment[68] only a few reports on its pharmaceutical properties have been found.[69]

Industrial Uses of Sulfonchloroamides. Aside from its use in the sterilizing of filters[70] and dairy equipment[71] and as a preservative[72] which depend upon its germicidal action, Chloramine T has been suggested for a number of industrial applications, particularly in connection with the processing of textiles. It is classed as a mild bleaching agent[73] especially suitable for rayon[74] and in the steeping process of bleaching crude cellulose.[75] It has also been advocated as a bleaching agent for dextrin used in the preparation of adhesives.[76] Aside from its bleaching action the most interesting property of Chloramine T from the standpoint of textiles is its solubilizing action upon starch[77] which is rendered useful for sizing. Chloramine T solutions have also been used in the desizing of cloth.[78] In the presence of copper or of copper and of iron salts the strength of linen is appreciably decreased.[79] Sodium benzenesulfonchloroamide, Chloramine B, has been recommended[80] as a substitute for the toluene derivative but has not come into general use.

Analysis and Detection of Sulfonchloroamides. Since Chloramine T has been introduced into a variety of products for one reason or another its detection and quantitative determination are of some importance. The "active chlorine" in a commercial product may be determined by titrating with sodium arsenite using starch-potassium iodide paper or by adding potassium iodide and titration of the liberated iodine with thiosulfate.[81] The oxidation of a sulfonated indigo in acid solution has also been studied.[82] To differentiate quantitatively between the Chloramine T and sodium hypochlorite in a solution the hypochlorite is first decomposed by hydrogen peroxide with which the Chloramine T reacts only slowly.[83] Qualitative distinctions between the sulfonchloramide and hypochlorites are numerous.[84] For example, manganese chloride turns brown with hypochlorite and not with Chloramine T; resorcinol gives a purple-red color with hypochlorite while a yellow to green color is produced by Chloramine T.

Special procedures for detecting Chloramine T in milk and cream[85] and in bread[86] have been described.

MISCELLANEOUS N-SUBSTITUTED SULFONAMIDES

Several classes of compounds are known in which a hydrogen of the sulfonamide group has been replaced by a substituent other than halogen, alkyl, or aryl. These include derivatives of hydroxylamine and hydrazine.

Derivatives of Hydroxylamine. The reaction of hydroxylamine with a sulfonyl chloride in alcohol solution gives the N-hydroxyamide[87] which is also commonly referred to as a sulfonhydroxamic acid. Compounds of this type containing an amino[87b] or acylamino[88] group in the *para* position have recently been found to exhibit therapeutic activity of the sulfanilamide type.

The sulfonhydroxamic acids undergo a number of interesting reactions. Oxidation with ferric chloride, iodine, and other reagents[87a] gives nitrous acid and the disubstituted hydroxylamine. Fuming nitric acid yields the trisulfonylamine oxide.

$$2C_6H_5SO_2NHOH + 2FeCl_3 + H_2O \rightarrow (C_6H_5SO_2)_2NOH + HNO_2 + 2FeCl_2 + 2HCl$$

Hydrolysis with alkali rather surprisingly yields the sulfinate.[87b,c;89]

$$2C_6H_5SO_2NHOH + 4NaOH \rightarrow 2C_6H_5SO_2Na + Na_2N_2O_2 + 4H_2O$$

Hydrolysis with dilute acid on the other hand produces the sulfonic acid and hydroxylamine. However, aqueous potassium carbonate has been reported[87b] to give the disulfone, $(ArSO_2)_2$.

The reaction of sulfanilhydroxamide with benzoyl chloride in sodium bicarbonate solution or in pyridine gives the N^4-benzoylsulfanilamide.[88a] It is not clear what was oxidized when the hydroxylamine residue was reduced. On the other hand, benzenesulfonhydroxamide reacts with acetic anhydride to give the N,O-diacetyl derivative.[87a]

In the presence of alkali, aldehydes react to give the sulfinate and the hydroxamic acid corresponding to the aldehyde.[90]

$$C_6H_5SO_2NHOH + RCHO + NaOH \rightarrow C_6H_5SO_2Na + RC(NOH)OH + H_2O$$

Ketones undergo cleavage of a carbon-carbon bond and one of the products is again a hydroxamic acid.[91]

The reaction of O-benzylhydroxylamine with a sulfonyl halide gives the N-benzyloxy-amide[92] which is stable toward alkali. It forms a nitroso compound that reacts with alkali with liberation of nitrogen. When an aqueous solution of sodium nitrite and a sulfinic acid salt is treated with acid the disulfonylhydroxylamine is formed.[87b,93]

$$2C_6H_5SO_2Na + NaNO_2 + 3HCl \rightarrow (C_6H_5SO_2)_2NOH + 3NaCl + N_2O$$

The dibenzenesulfonyl derivative has also been obtained from benzenesulfonamide by treatment with sodium nitrite and sulfuric acid.[94]

A disulfonyl compound reacts with alkali to yield the sodium sulfinate and sodium nitrite,[93a] while with acid the products are the sulfonic acid and hydroxylamine.[87c] Treatment with nitrous oxides,[93a] nitrous acid,[87b] a sulfonyl chloride, or a sulfinic acid[87b] forms the trisulfonylamine oxide. However, with benzoyl chloride the benzoate results normally.

The trisulfonylamine oxides mentioned above have also been obtained from the sulfinic acids and fuming nitric acid or nitrogen tetroxide.[95] With alkali the substituted amine oxide gives the salts of sulfinic and nitric acids[87c] whereas with acid the sulfonic acid and hydroxylamine result.

Derivatives of Hydrazine. The formation of sulfonhydrazides and their decomposition reaction to sulfinic acids have been described in the section on reactions of sulfonyl chlorides (p. 502). Several other characteristic reactions are known. Benzenesulfonhydrazide[96] reduces alcoholic silver nitrate and Fehling's solution. Iodine in alcohol gives phenyl disulfide as one product. Benzenesulfonazide is formed as a yellow oil when the hydrazide is treated with sodium nitrite and acetic acid.

$$C_6H_5SO_2NHNH_2 + HNO_2 \rightarrow C_6H_5SO_2N_3 + 2H_2O$$

Decomposition of the hydrazide by refluxing with water or alcohol gives hydrazine and the sulfonic acid while hydrolysis of the azide by acid or alkali very slowly yields the sulfonic acid and hydrazoic acid. Reduction of the azide with zinc and acetic acid gives rise to benzenesulfonamide.

The sulfonhydrazides react with aldehydes and ketones just as do other hydrazine derivatives except that the reaction seems to be slower. The sulfonhydrazones are generally solids of possible use in identification of carbonyl compounds.

The reaction of an acyl halide leads to substitution on the second nitrogen.

$$C_6H_5COCl + C_6H_5SO_2NHNH_2 \rightarrow C_6H_5CONHNHSO_2C_6H_5 + HCl$$

Compounds of this type have been found to decompose in ethylene glycol at 160° in the presence of sodium carbonate to give the aldehyde.[97] The decomposition does not give the aldehyde, however, when the acyl group is derived from *p*-nitrobenzoic, cinnamic, diphenylacetic, or an ordinary aliphatic acid. The synthesis is useful for pyrimidine[98] and thiazole[99] aldehydes and has also been applied to the synthesis of thyronine.[100]

Nitroso and Nitrosulfonamides. The sulfonamides of aliphatic primary amines[101] and of α-amino acids[102] react with nitrous oxides or nitrous acid to give N-nitroso derivatives. Benzenesulfonmethylnitrosoamide acts as a methylating agent toward phenols and converts morphine to codeine.[101]

The action of nitric acid on benzenesulfonamide [103] or a benzenesulfonalkylamide [104] gives the corresponding N-nitro compound. The alkylnitroamides have also been prepared by the reaction of an alkyl iodide with the silver salt of a nitrosulfonamide.[103] Upon heating,

$$C_6H_5SO_2N(NO_2)Ag + CH_3I \rightarrow C_6H_5SO_2N(NO_2)CH_3 + AgI$$

benzenesulfonnitroamide decomposes to give the sulfonic acid and nitrous oxide.[103] Reduction with stannous chloride results in recovery of the sulfonamide but hydrogen iodide yields the disulfide, and zinc in acetic acid produces a complex mixture which includes the sulfinic acid, ammonia, the sulfonhydrazide, and the disulfonhydroxamide.[105]

SACCHARIN AND RELATED COMPOUNDS

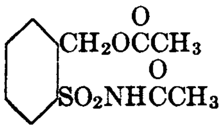
The discovery by Remsen and Fahlberg [1] that the benzoic sulfinide (benzoic sulfimide, 2,3-dihydro-3-oxobenzisosulfonazole) obtained by them through the oxidation of *o*-toluenesulfonamide has an intensely sweet taste led to the comprehensive investigation of the manufacture, the derivatives, the detection in many types of consumers' goods, and the physiological action of this interesting compound. In addition numerous articles and even a book have been written on the utilization of the by-products (chiefly *p*-toluenesulfonyl chloride) obtained in its manufacture. Because the sweetening effect of saccharin, which is some five hundred times that of sucrose, makes possible its substitution for sugar in a variety of products, laws controlling its sale and use have been passed in every civilized country. Although the legal status of saccharin cannot be dealt with here in adequate fashion other aspects of its production and use will be covered in some detail.

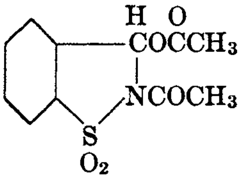
Methods of Preparation. The most important methods for preparing saccharin depend upon *o*-toluenesulfonamide as the starting material. Since the sulfonation of toluene (see p. 202) at best gives not more than 60% of the *o*-sulfonic acid or sulfonyl chloride it is necessary to separate this from the *para* isomer or to separate the mixture of sulfonamides. As McKie has shown,[2] in the usual procedures partial separation occurs at each stage, the final product containing 90–93% *ortho* and the remainder *para* sulfonamide. Further separation may be brought about by extraction of the amide mixture with aqueous sodium carbonate, by solution in alkali and partial (70%) precipitation by acetic acid, or by recrystallizing from 50% alcohol. The acetic acid precipitation gives a 99.5% pure *ortho* amide but the loss is about

30%. The sodium carbonate extraction gives the best results, everything considered. A method that does not depend upon solubility consists in the oxidation of the mixture with a small amount of potassium permanganate.[2] This oxidizes the *para* amide completely; 90–94% of the *ortho* isomer is recovered together with from 5 to 9% of pure saccharin. In a thorough review of the saccharin industry Terlinck [3] describes a process for separating completely the *ortho* and *para* toluenesulfonic acids by precipitating the former as the barium salt, eliminating the necessity of separations in later steps.

Remsen was led to investigate the oxidation of *o*-toluenesulfonamide because preliminary experiments using chromic acid mixtures [4] had shown the *ortho* compound was practically unaffected when a mixture of the two isomers was oxidized. In the first permanganate oxidation [1] 5 g. of *o*-benzoic sulfinide and 4 g. of potassium *o*-sulfobenzoate [5] were obtained from 10 g. of *ortho* amide. The initial presence of one molecular equivalent of potassium or sodium hydroxide [5,6] increases the yield of saccharin 10–15% and the permanganate needed is diminished. The temperature is best kept below 60° to prevent hydrolysis of the product.

Although the oxidation of *o*-toluenesulfonamide with chromic acid is slow in dilute acid,[4] in strong sulfuric acid [7] (over 50%), particularly in the presence of iron, chromium, or manganese salts,[8] the reaction proceeds satisfactorily. Best results are obtained at 50–60° with 70% sulfuric acid, the yield of saccharin approximating 90% of the theoretical amount. In an attempt to determine the mechanism of the chromic acid oxidation it has been carried out in acetic anhydride solution [9] at from −5 to 30°. In addition to acetylsaccharin and N-acetyl-*o*-toluenesulfonamide a diacetate believed to have one of the accompanying formulas was isolated.



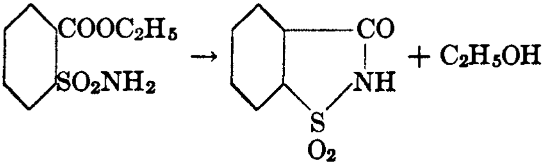


Another compound of unknown structure was also present in the mixture.

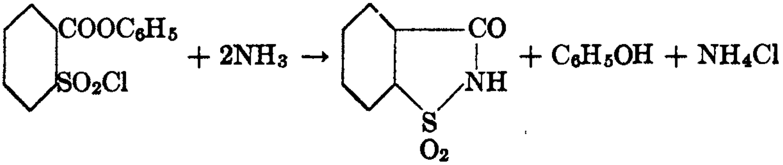
The electrolytic oxidation of *o*-toluenesulfonamide is of practical value [10] if the reaction is carried out in alkaline solution. In acid solution the yield is very poor while in 2 *N* sodium carbonate [11] at 60° it reaches 75% of the theoretical amount. The yield is much less in an ammonium sulfate-ammonium hydroxide mixture. Electrolytic oxidation using potassium permanganate as the oxygen carrier has been patented.[12] A number of reviews of the manufacturing processes for saccharin have appeared in the literature.[13]

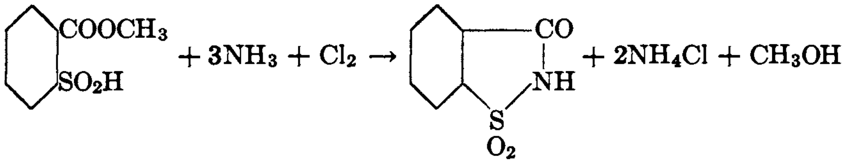
The observation by Noyes [14a] that oxidation of *o*-toluenesulfonamide with potassium ferricyanide in strongly alkaline solution gives not saccharin but *o*-sulfonamidobenzoic acid should be mentioned. Until this experiment the independent existence of this acid was doubted, and, since the salts of saccharin were hydrated they were believed to be salts of the acid rather than the compound with the ring structure. Noyes found the salts of the acid to be quite distinct from those of saccharin.

Saccharin has been obtained, at least in the laboratory, by a number of methods not directly involving *o*-toluenesulfonamide. In general, any compound having carbon, nitrogen, and sulfur atoms located in adjacent positions in the benzene ring can be converted to saccharin provided the sulfur and carbon are attached to the ring. *o*-Sulfonamidobenzoic acid is readily dehydrated by brief heating [14] at 155°, or better,[15] at 114–116° for a long time; by the action of phosphorus oxychloride,[16] and by the action of oleum [14b] below 40°. Esters of this acid, either by heating in water or alkali,[17] give saccharin rather than the acid.



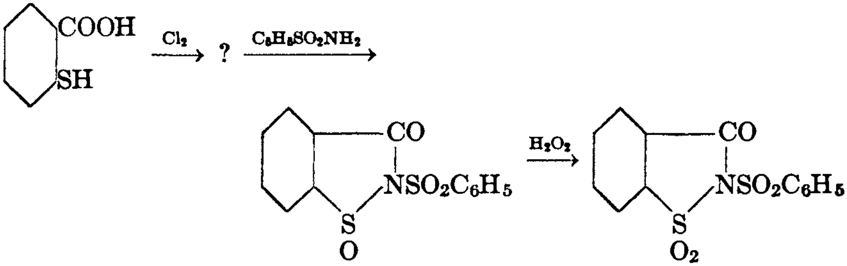
o-Cyanobenzenesulfonamide [18] likewise yields the cyclic compound when refluxed with dilute sodium hydroxide. Bis-(*o*-carbamylphenyl) disulfide [19] is oxidized by permanganate to saccharin. Saccharin also results from the action of ammonia upon the stable dichloride derived from *o*-sulfobenzoic acid [20] or upon phenyl *o*-chlorosulfonylbenzoate,[21] and from the action of ammonia and chlorine upon methyl *o*-sulfinobenzoate [22a] in alcohol.



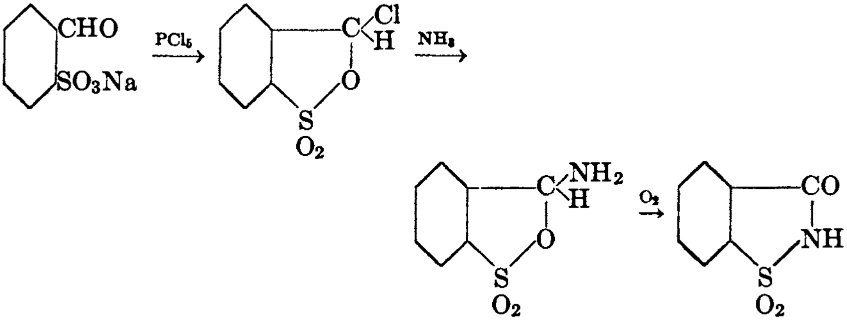


Saccharin is a minor product when Chloramine TO, sodium *o*-toluenesulfonchloroamide, is heated with 2.5% acetic acid[22b] at 100°.

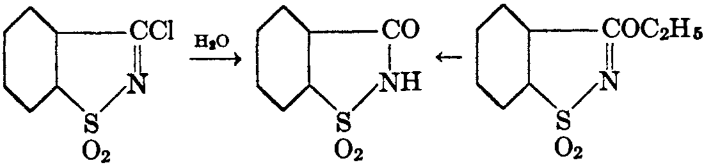
When the chlorination product of *o*-thiolbenzoic acid is allowed to react with an amide and the product oxidized, a saccharin derivative, and in one case saccharin itself, is produced.[22c]



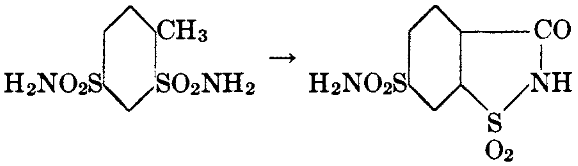
Finally, the conversion of several cyclic compounds into saccharin may be mentioned. The action of phosphorus pentachloride upon *o*-sulfobenzaldehyde[23] gives a chloride which yields an amine that oxidizes to saccharin in the air.

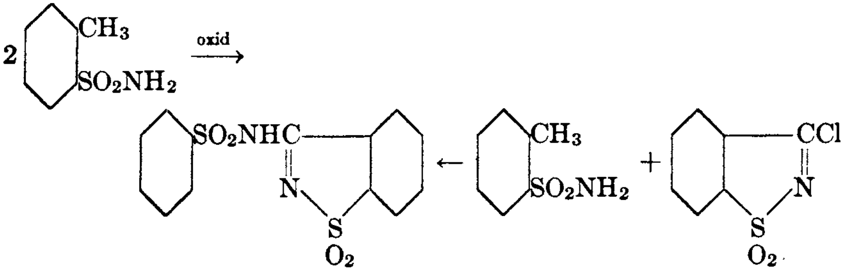


The chloride obtained from saccharin by treatment with phosphorus pentachloride or by the action of chlorine in water[24] is readily reconverted to saccharin, as is the corresponding ether.[24b]



By-Products of Saccharin Manufacture. Depending upon the particular process employed, there are obtained as by-products in saccharin manufacture *p*-toluenesulfonic acid, the sulfonyl chloride, and the amide. In addition a number of other substances have been isolated which are produced in lesser amounts. These include toluene-2,4-disulfonamide which on oxidation gives 6-sulfonamidosaccharin,[25a] and a very bitter compound formed in small amount which has been shown [25b] by synthesis from pseudo-saccharin chloride and *o*-toluenesulfonamide to have the accompanying formula.





Utilization of these by-products has been discussed at great length by Herzog.[26] The chemistry involved in these applications is for the most part considered in other sections. Aside from the hydrolysis of *p*-toluenesulfonic acid or the acid chloride to toluene the by-products have been used directly or indirectly [3] in preparing alkyl *p*-toluenesulfonates (alkylating agents), Dichloramine and Chloramine T, in condensing phenols with aldehydes, in the tanning industry, in the preparation of photographic developers, and in the control of insects and weeds, if one is to take the patent literature as a criterion. *p*-Toluenesulfonamide has been used as a camphor substitute, and by condensing with formaldehyde, in the synthesis of resinous materials (see p. 585).

Physical and Physiological Properties of Saccharin. Saccharin is an acid of moderate strength with the dissociation constant 9.86×10^{-8} at 100 l. dilution and 4.53×10^{-8} at 800 l.[27] It therefore decomposes carbonates readily and the pills of saccharin and bicarbonate in which it occurs commercially gradually lose carbon dioxide.[28] Although it ordinarily acts as a monobasic acid, yet when shaken in ether solution with solid sodium or potassium hydroxide [29a] two or three moles of the alkali react. Di- and tri-mercurated compounds have also been made.[29b]

Saccharin dissolves in thirty times its weight of water at 100° and in three hundred twenty-five parts at room temperature.[30] The crystals are triboluminescent.[31]

Since Remsen and Fahlberg [1] first reported that their benzoic sulfinide had a remarkably sweet taste this property has been the subject of many investigations. The flavor of saccharin is not exactly the same [32] as that of sucrose. The sweetness varies from 200 to 700 times that of sucrose, depending upon the dilution; [33] that is, the effectiveness is greater in more dilute solution. For example, 1.41 g. of the sodium salt in 1 kg. of water gives a solution equivalent in taste to a sucrose syrup of density 1.30 and 1.61 g. of such a solution is equivalent to 1 g. of sucrose [34] while a liter of solution containing 0.055 g. of saccharin is equivalent in taste to about a 3% sucrose solution.[35] This variation is more or less [13a] parallel with the variation in molar conductivity of the sodium salt on which the test was made; hence the taste has been ascribed to the anion. Although repression of the ionization with sodium ions has been reported in one instance to decrease the sweet taste, other investigators have not agreed with this,[36a] and since the taste persists in acid solution the anion alone can hardly be responsible. Incidentally, saccharin decreases the "sourness" of hydrochloric acid to about the same extent that sucrose does.[36b] It is further interesting to note that the relative sweetness increases with increasing concentration of alcohol in aqueous-alcohol solutions.[37] The sweetness of saccharin is also increased by the presence of another sweetening agent, dulcin.[38] Thus a solution containing in 1 l. 120 mg. of dulcin and 280 mg. of saccharin is equivalent to one containing 535 mg. of saccharin alone and the mixture was reported to have a more pleasant taste than the saccharin solution. Dulcin has a smaller sweetening action than saccharin when alone in solution. Dulcin and urea diminish the unpleasant aftertaste of saccharin.[38c]

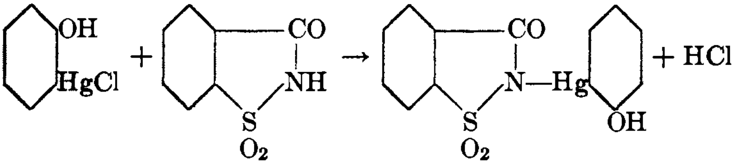
It has been claimed that one-half or more of the sucrose used in making up a sweetened foodstuff may be replaced by saccharin before the taste of the latter becomes noticeable.[39] However, if the product contains organic acids and is boiled hydrolysis occurs to a sufficient extent to change the taste.[40a] The use of saccharin in the preparation of various drugs has been discussed.[40b]

Not only is saccharin used as a sweetening agent for those, such as diabetics, who need a low sugar diet but also in time of carbohydrate scarcity it may come into more general use. It has been reported [41] that in Germany in 1917–1919 about 1000 tons of artificial sweetening agents replaced some 200,000 tons of sugar. At about the same time it was recommended for use in Italy [42] in order to save sugar for children, invalids, and soldiers. The utilization of fodder by an animal is increased by addition of saccharin, but the expense involved made this impractical.[43] This widespread use and contemplated use of saccharin have led to many investigations upon its physiological action.

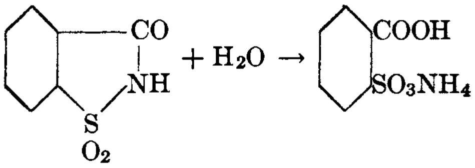
There is apparently no case on record where a human illness has been ascribed to the use of saccharin in normal amounts. One nine-year-old boy who ate 200 saccharin tablets became seriously ill but promptly recovered.[44] In feeding experiments of men [45] and animals,[46] the latter experiments extending over several generations, no deleterious effects have become obvious. It has no effect upon diastatic action of saliva [47] or upon peptic and tryptic digestion; the gastric secretion [48] is increased or unaffected. The activity of vitamins is not changed.[49] When administered with glucose it inhibits greatly the resulting hyperglucemia.[50]

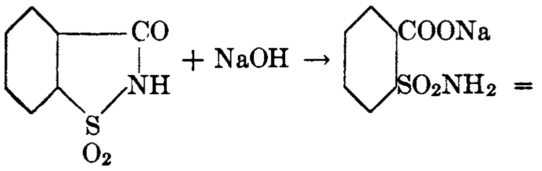
A few investigators have concluded that saccharin is not entirely harmless. Carlson and co-workers [51] summarized their results by saying: "Saccharin acting in the mouth decreases gastric appetite secretion, in the stomach it increases gastric secretion and decreases peptic digestion, in the small intestine it decreases absorption; acting on erythrocytes it decreases hemolysis. These reactions cannot be explained by the osmotic factor. Saccharin in the blood, in proportion to its concentration, passes into the lymph, cerebrospinal fluid, saliva, tears and mammary secretion." Continuous and general use was not regarded as harmless. Heitler [52] believed that it should not be used at all because of its depressant action upon the heart. In feeding dogs large amounts of saccharin over a period of 100 days the only effect was diffused hyperemia in the kidneys, lungs, myocardium, and liver [46c] which suggests that it is not entirely innocuous. It is excreted unchanged in the urine.

Saccharin has been reported [53] to have a marked bactericidal action, greater than that of phenol, but this seems to be somewhat exaggerated.[54a] The phenylmercuric [54b] and *o*-hydroxyphenylmercuric [54c] salts have a marked inhibitory effect upon bacterial growth but this may be credited to the mercury part of the molecule. The method utilized in preparing these compounds is indicated by the equation.



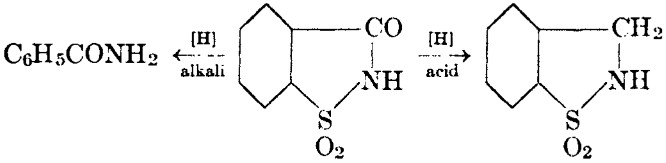
Reactions of Saccharin: Hydrolysis and Reduction. Because of the stability toward hydrolysis shown by phthalimide and sulfonamides it might be expected that saccharin would hydrolyze only slowly in strong acid or alkali. Actually, hydrolysis occurs with water alone, although the reaction is slow. Boiling a water solution results in 97.4% hydrolysis in 96 hours[55] and at room temperature 17.6% hydrolyzes in 166 days. By comparison of absorption spectra measurements the per cent hydrolyzed in 0.001 molar solution in 2 hours at various temperatures[56] is as follows: 100°, 3%; 125°, 12%; 150°, 55–60%; 200°, 80–86%; 250°, 90–94%. The sodium salt is more stable, hydrolysis amounting to only 6% at 230° in 2 hours. With boiling dilute alkali conversion to *o*-sulfonamidobenzoic acid occurs with considerable rapidity[57] and the change stops at this stage.





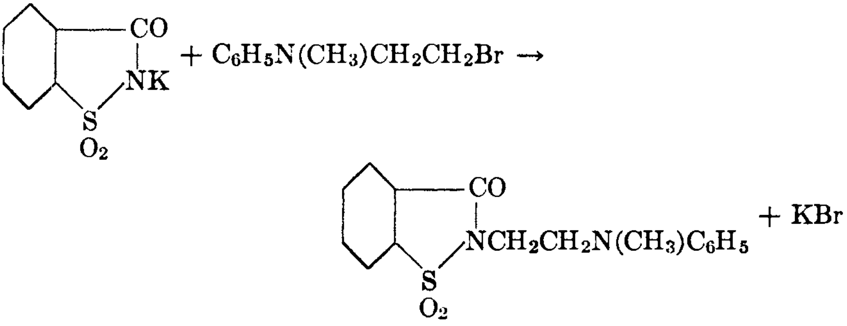
The reaction is bimolecular with $k_{100} = 0.020$. In the acid hydrolysis[57b, 58] as in water alone the product is an ammonium salt. This reaction is reported to be monomolecular and independent of the acid concentration with $k_{100} = 0.045$. The ease of hydrolysis of saccharin has been utilized many times in developing analytical procedures; the ammonium salt resulting from acid hydrolysis is treated with alkali and the ammonia determined in one of the usual ways.[59] Ammonia is not liberated easily from *p*-sulfonamidobenzoic acid, one of the common components of commercial saccharin, hence this does not interfere in the analysis.

Ammonia is also eliminated from saccharin by reduction with sodium and amyl alcohol[60a] but the reaction proceeds much farther. The sulfo group is then eliminated as sodium sulfite and the ring is reduced; the final product is hexahydrobenzoic acid. On the other hand electrolytic reduction[60b] in acid solution finally gives benzylsultam.

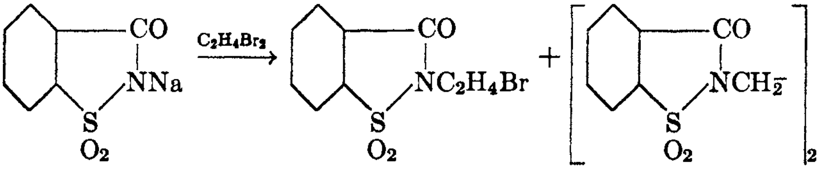


However, in 3% aqueous alkali the products are benzamide, then benzaldehyde and hydrobenzoin, elimination of sulfur occurring as in the sodium and alcohol reduction.

Alkylation and Acylation. Heating the potassium or sodium salt of saccharin with an alkyl halide[61] results in alkylation of the nitrogen only. The reaction is slow with ethyl iodide in alcohol solution under reflux but this and less active halides react readily in butyl Carbitol-water mixtures. Several more complex halides have been shown to react. Alkylation occurs readily with β-(phenylmethylamino) ethyl bromide,[62] with ethyl chloroacetate,[63a] and with chloroacetone and phenacyl bromide.[63b] Ethylene bromide[64] gives both possible reaction

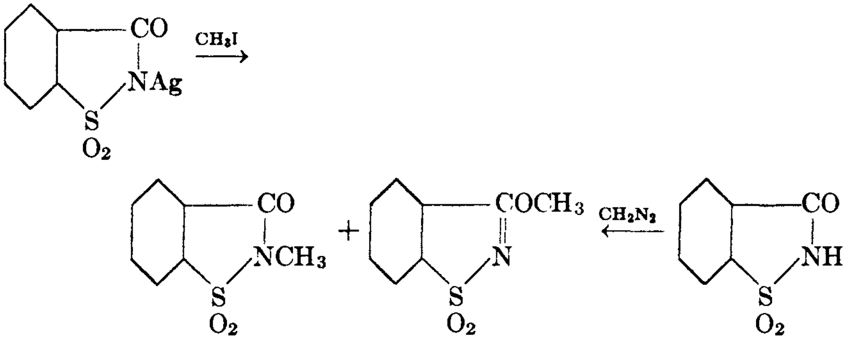


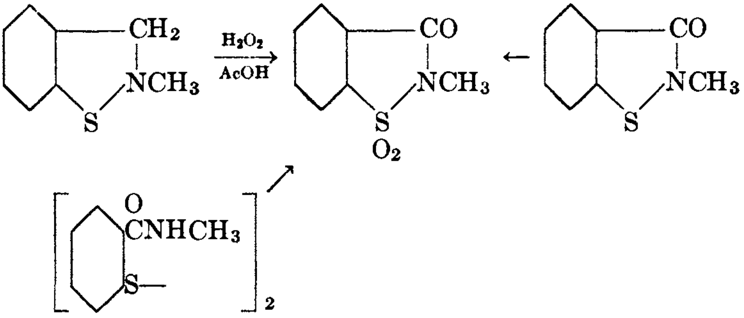
products after 40 to 50 hours of refluxing in alcohol.



Both bromines of tetramethylene bromide have been replaced by saccharin residues.[65] The *p*-nitrobenzyl compound has been recommended as a derivative suitable for identification [66] of the halide.

By treating the silver salt of saccharin with an alkyl iodide both the N- and O-alkyl derivatives result.[67] The oxygen compound has also been obtained in 20% yield from the action of diazomethane upon saccharin itself. The structure of the N-alkyl compounds is evident from their synthesis from alkylamines and *o*-chlorosulfonylbenzoyl chloride.[68] They have also been obtained by refluxing saccharin with dimethylaniline,[69] by oxidation of the benzisothiazole [70] or isothiazolone,[71] and by oxidation of the bis-(*o*-methylcarbamylphenyl) disulfide.[70]

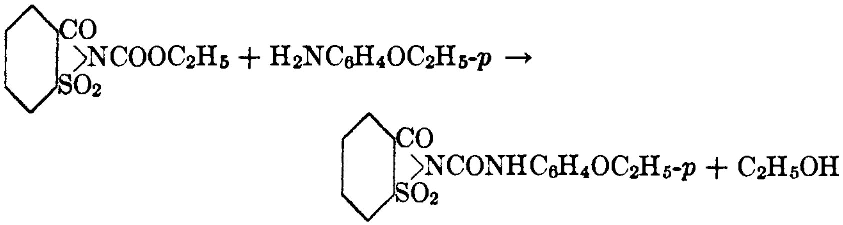




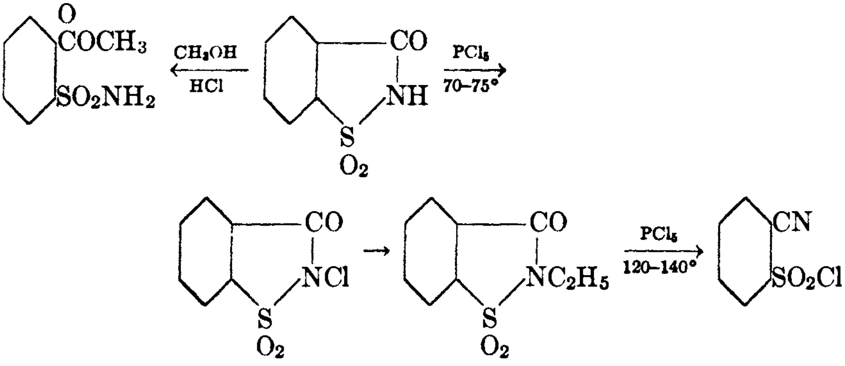
N-Picrylsaccharin has been prepared by the action of picryl chloride upon the sodium salt [63a] of saccharin. Several other arylsaccharins have been obtained by indirect syntheses.[72]

The action of an acid chloride or anhydride upon saccharin or its sodium salt gives only the N-acyl derivative.[67, 73a,b] Likewise the action of the silver salt with acetobromoglucose [73c] gives only the N-compound.

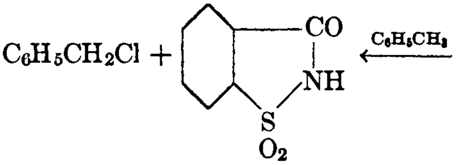
The action of *p*-phenetidine on ethyl saccharin-N-carboxylate gives a compound which is a derivative of both saccharin and dulcin but it does not have a sweet taste.[73d]

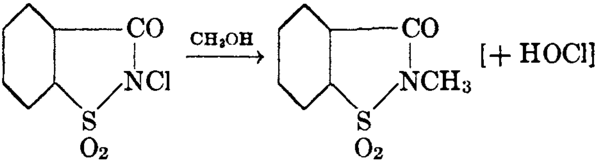


Miscellaneous Reactions. When heated with methanol [74] to 170° or at a lower temperature in the presence of hydrogen chloride [24h] saccharin undergoes alcoholysis. Another ring cleavage reaction is the one occurring with phosphorus pentachloride [24] at 120–140°. If the temperature is kept at 70–75° the resulting compound with alcohol yields N-ethylsaccharin,[75] and hence is probably N-chlorosaccharin.



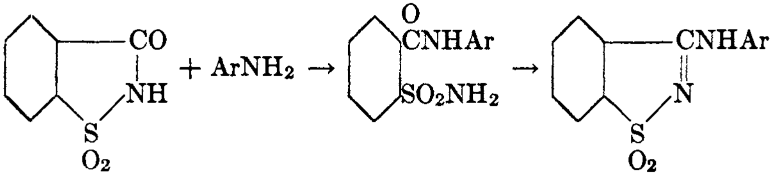
Heating saccharin with potassium chlorate and dilute hydrochloric acid gives an excellent yield of *o*-chlorobenzoic acid [76] whereas with a concentrated acid (1 to 1) there is formed a nitrogen compound in high yield. This was believed [77] to have the structure of an open-chain imide. The action of chlorine on the sodium salt, however, gives N-chlorosaccharin in good yield [78] while with saccharin itself chloro-*pseudo*-saccharin results. It may be mentioned that the chlorosaccharin reacts with methanol to give N-methylsaccharin. With toluene the side chain is chlorinated in practically quantitative yield after 2 hours of refluxing.



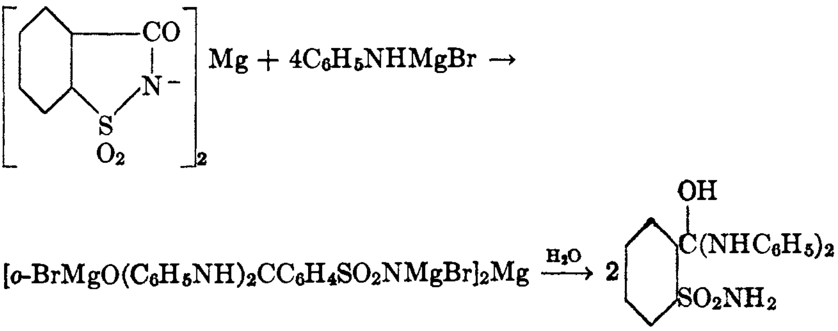


The N-iodosaccharin results from the action of iodine upon the silver salt.[79, 80]

When saccharin is treated with an aromatic amine at room temperature the simple ammonium salt is formed, but when heated to near the boiling point ring cleavage occurs.[75, 81] N-Methylaniline reacts similarly at first but upon long boiling N-methylsaccharin results, a product also formed with dimethylaniline. The primary amines after long heating produce *pseudo*-saccharin derivatives as shown in the equation.

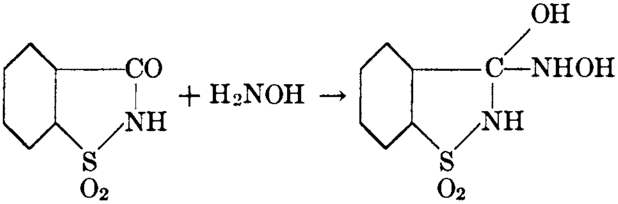


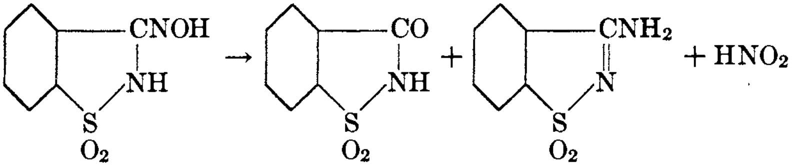
When saccharin is added to an ether solution of phenylaminomagnesium bromide($C_6H_5NHMgBr$) hydrolysis of the reaction mixture yields a cleavage product presumably formed by the reactions shown herewith.[82] Other analogous compounds were prepared and their



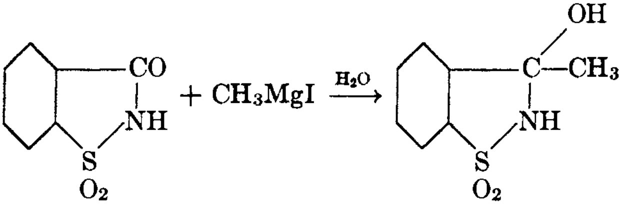
chemical properties investigated. The suggested structures for the final products are not certain.

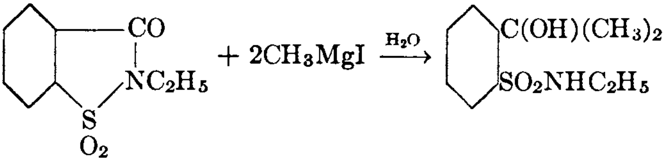
The carbonyl group in saccharin does not yield an oxime. Reaction with hydroxylamine occurs readily in alcohol, however, to give an addition compound[83] whose properties have been exhaustively studied. It is readily reconverted to saccharin by treatment with concentrated sulfuric acid or dilute nitric acid, by heating with acetic anhydride, and by heating alone at its melting point (157°). It is an acid which decomposes carbonates readily. The true saccharin oxime was obtained from thiosaccharin and hydroxylamine, hydrogen sulfide being evolved. The oxime when heated slowly to the fusion point decomposes with evolution of nitrous acid leaving a residue consisting of a mixture of saccharin (60–70%) and *pseudo*-saccharinamine.[84]



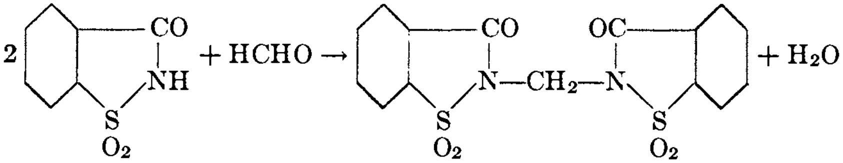


The carbonyl group adds a Grignard reagent to give a hydroxy compound that is tasteless and insoluble in alkali.[85] This lack of acidic properties raises the question of the correctness of the assigned structure but the compound did yield a dibenzoyl derivative. It should be mentioned that the N-alkylsaccharins undergo ring cleavage with Grignard reagents;[86] it is surprising, perhaps, that saccharin does not behave similarly.

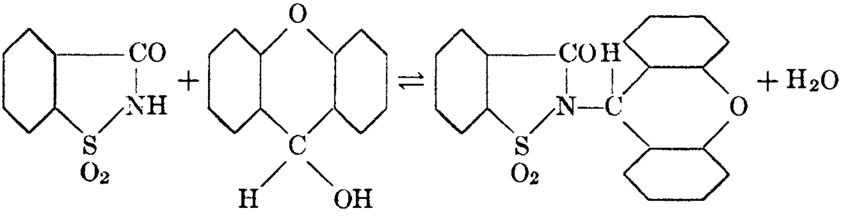




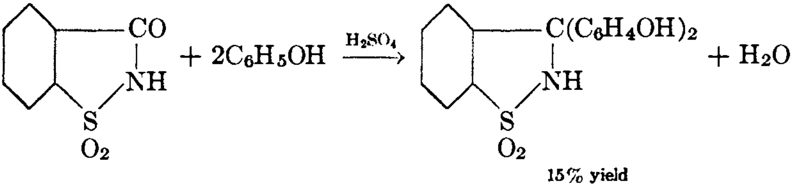
The imide group of saccharin condenses readily with formaldehyde to give the hydroxymethyl compound.[87] In the presence of 70% sulfuric acid two moles of saccharin react.[64]



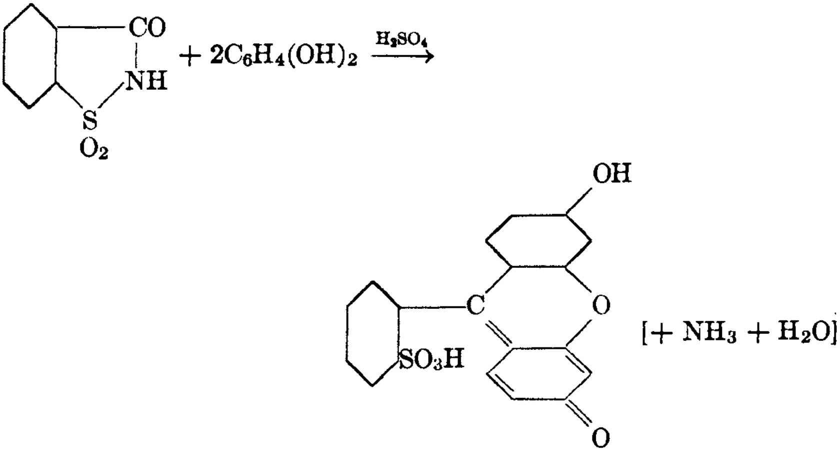
The reactive hydroxyl in xanthhydrol also condenses with the imide hydrogen;[88] the product is readily hydrolyzed by acid.



The condensation of phenols with saccharin in the presence of sulfuric acid or zinc chloride[89] leads to the formation of compounds analogous to the phthaleins which have been named sulfamphthaleins.



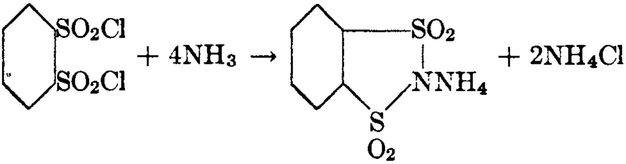
Compounds of this class have been obtained from phenol, resorcinol, orcinol, phloroglucinol, hydroxyhydroquinone, catechol, 1,2,4,5-tetrahydroxybenzene, and also from *m*-aminophenol, *m*-dimethylaminophenol, and phenylenediamine. Aluminum chloride has also been employed as the condensing agent[90] in reactions involving resorcinol and *m*-dimethylaminophenol. By heating saccharin and resorcinol with sulfuric acid at 135–140° for 7 hours a 52% yield of sulfonefluorescein results, the nitrogen being eliminated.[91] In this condensation Dutt[89] used zinc chloride to obtain the sulfamphthalein, the nitrogen being retained.



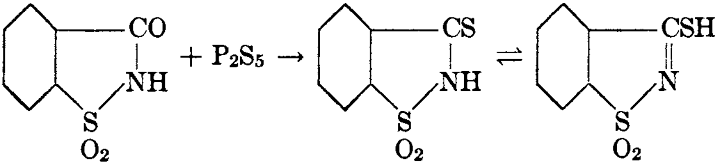
Detection and Determination of Saccharin. Because of the multiplicity of uses to which an inexpensive synthetic sweetening agent may be put and because of legal restrictions upon its use the problem of analyzing foods, drugs, and drinks for saccharin has of necessity received much attention.[92] Determinations carried out by hydrolysis of saccharin to ammonia have already been mentioned.[59] Any such procedure must be preceded in practice by the isolation of the saccharin which may be present in only small amounts. It is insoluble in petroleum ether but quite soluble in ethyl ether and is usually extracted with this or a mixture of ethyl and petroleum ether.[93] Once pure or nearly pure saccharin is isolated it may be identified in a number of ways. Identification by microscopic examination of the crystals[94] or of salts formed with various reagents[95] has been developed in detail. Fusion with alkali to give salicylic acid and determination of this with ferric chloride[93e] or of the sulfur as barium sulfate[93f,96] frequently has been utilized. An ingenious method developed a few years ago[97,98] involves suspending a filter paper or asbestos mat impregnated with magnesium oxide in the ether solution of the saccharin. After all the saccharin collects on the mat it may be fused with alkali to give salicylic acid. Adsorption on bone charcoal has also been recommended.[99]

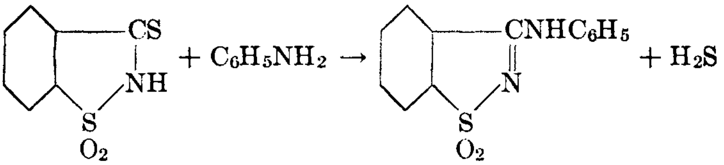
A colorimetric method that has been rather frequently used depends upon hydrolysis of the saccharin to *o*-sulfobenzoic acid and conversion of this to phenolsulfonephthalein[100] by heating with phenol and phosphorus pentoxide or sulfuric acid. The product gives a red color in alkaline solution. A number of other miscellaneous methods and procedures as well as applications of methods already mentioned are to be found in the literature.[101]

Analogs of Saccharin. Since replacement of a carbonyl in the tasteless phthalimide by a sulfone group brings about such a remarkable change in flavor the effect of further substitutions and alterations has been investigated. The action of ammonia upon *o*-benzenedisulfonyl chloride was first reported[102] to give the diamide but Holleman[103] has shown that this is actually the ammonium salt of *o*-benzenedisulfonimide. A 0.1% solution of the salt has a distinctly sweet taste but apparently no quantitative comparison with saccharin has been made. The ammonium salt has been converted to the sodium and calcium salts by treatment with the appropriate base. The free imide, obtained from the barium salt as hygroscopic crystals, m.p.192°, is extremely soluble in water, and has at once a sweet and acid taste with a bitter aftertaste.



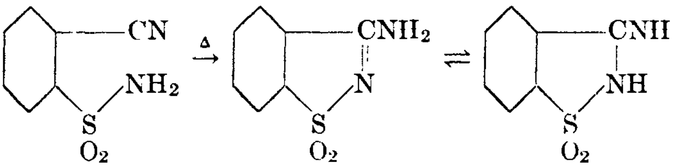
Heating saccharin to 220° with phosphorus pentasulfide gives as high as 90% yields of thiosaccharin.[104] This has a bitter taste and mixed with saccharin gives a mild taste. It is easily hydrolyzed, reaction occurring even on long boiling with water, with formation of saccharin and hydrogen sulfide. The methyl derivative obtained by the action of methyl sulfate was assumed to have the alkyl group on the nitrogen although it may have the sulfide structure. Acidic and alkaline hydrolytic agents act on thiosaccharin to give the same products that result from saccharin, ammonium *o*-carboxybenzenesulfonate and *o*-sulfonamidobenzoic acid respectively. As already mentioned (see p. 628) hydroxylamine gives the oxime which has an insipid taste.[88] Warming thiosaccharin with aromatic amines leads to a vigorous reaction[105] with evolution of hydrogen sulfide and formation of



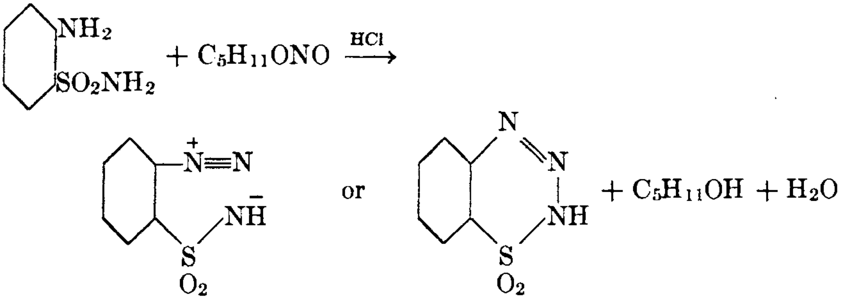


pseudo-saccharin derivatives.

Another analog of saccharin is the *pseudo*-saccharin amide obtained by the action of ammonia upon *o*-cyanobenzenesulfonyl chloride,[24b] from *o*-cyanobenzenesulfonamide by fusion, or by treatment with aqueous ammonia,[84b] and from *pseudo*-saccharin chloride or ethyl ether, and ammonia.



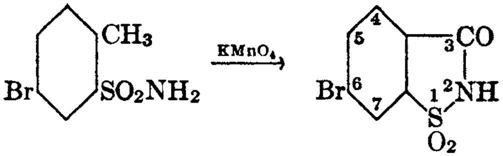
An interesting substance somewhat further removed from saccharin than the foregoing but which does possess a sweet taste is that obtained from amyl nitrite and *o*-aminobenzenesulfonamide.[106] From the electronic standpoint the compound could have either of the two structures



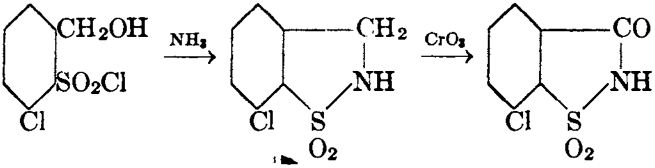
shown. That it does not contain the heterocyclic six-membered ring is evident from its lack of color, insolubility in ether, and instability toward heat.

Saccharin Derivatives. Known derivatives of saccharin range from those in which a hydrogen has been replaced by an atom or group to compounds derived from naphthalene or biphenyl but which still contain the typical heterocyclic nucleus of the benzoic sulfinide. Saccharin derivatives obtained by replacing the imide hydrogen by various substituents have been mentioned under the reactions of saccharin. Those in which the benzene ring has been modified will now be considered.

The 6-halosaccharins have been prepared by oxidation of the corresponding toluene derivatives[107] and the bromine compound has also

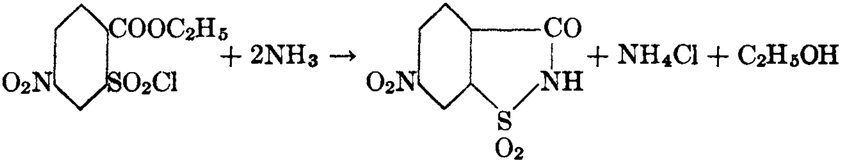


been obtained from isomeric 4-bromobenzene-2-sulfonylbenzoyl chlorides[108] by the action of ammonia, and from the hydrolysis of 4-bromo-2-sulfonamidobenzonitrile.[109] The taste of these compounds becomes increasingly bitter with increase in the atomic weight of the halogen. There is a marked variation in the taste of the isomeric chlorosaccharins. 5-Chlorosaccharin[110] obtained from *m*-chlorotoluene through sulfonation, conversion of the sulfonic acid to the amide, and oxidation has a sweet taste with an intense and persistent bitter aftertaste. Davies[111] found that 4-chlorosaccharin, prepared from 6-chlorotoluene-2-sulfonyl chloride, is about half as sweet as saccharin but has a somewhat astringent taste. The fourth isomer, 7-chlorosaccharin[112] has been described as intensely sweet. The method of synthesis for this compound is outlined below.



Tetraiodosaccharin has been prepared from the tetraiodo-*o*-sulfobenzoic anhydride and ammonia.[113] It has a faintly bitter taste and, interestingly enough, it was found to be insoluble in sodium hydroxide and would not condense with phenols. The crystals showed no sign of melting at 345°.

In 6-nitrosaccharin the sweet taste is entirely lost, and the flavor has become exceedingly bitter. In addition to the usual preparation by oxidation of the toluene derivative[114] and from the acid dichloride[115] it has been obtained from ethyl 4-nitro-2-chlorosulfonylbenzoate and ammonia.[115] The amine obtained from the nitro compound



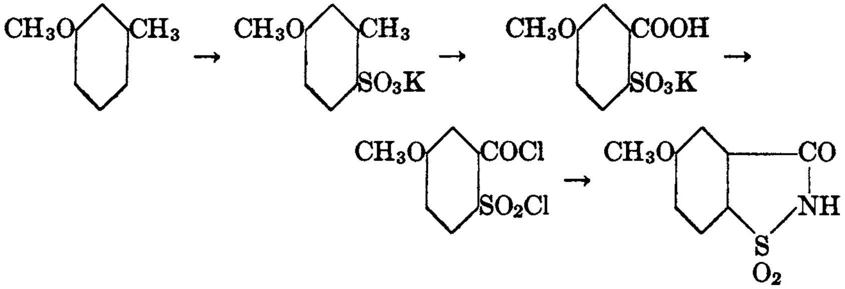
has a sweet taste,[114] but a number of acyl derivatives and ureas made from it do not,[73d] including the disaccharin urea and saccharin-6-dulcin. The N-methyl, -ethyl, and -phenyl derivatives of the nitro compound were prepared in the usual ways.

In 6-methylsaccharin, obtained from the sulfonamidotoluic acid or the tolunitrile,[116,117] the taste is not greatly different from that of saccharin although a quantitative comparison is lacking. It is hydrolyzed by boiling with water to the sulfonamidotoluic acid and with potassium hypochlorite at 80° gives 4-aminotoluene-3-sulfonic acid. Since alkaline hydrolysis always yields the sulfonamide the reaction apparently proceeds without intermediate formation of the amide of the carboxyl group. It has been observed that N-chlorosaccharin[78] with cold alkali and then acid yields N-chlorosulfonamidobenzoic acid.

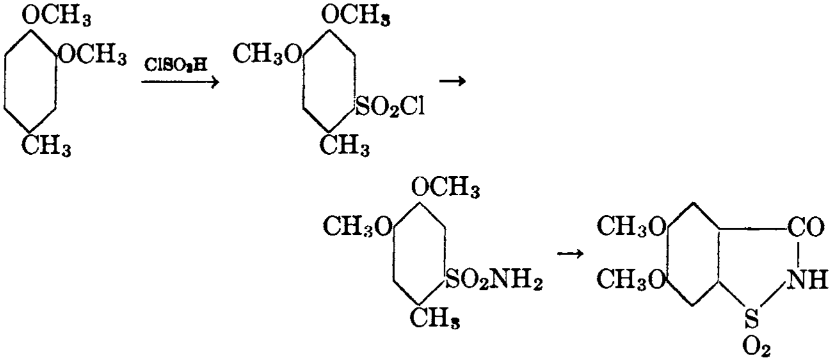
Unlike the dialkylbenzenesulfonamides, mesitylenesulfonamide oxidizes first at the methyl adjacent to the sulfonamide group.[118] The resulting 5,7-dimethylsaccharin was also prepared from 3,5-dimethyl-2-chlorosulfonylbenzoyl chloride and ammonia.[118b] It differs from other saccharin derivatives in that hydrolysis with acid at a high temperature yields a sulfur-free product, mesitylenic acid, while fusion with sodium hydroxide gives this acid and some 2,4-dimethylbenzenesulfonamide.

6-Hydroxysaccharin[73d] has been prepared from the amine through diazotization and hydrolysis. It has an intensely sweet taste, probably more pronounced than saccharin itself. The hydroxy compound has been coupled with diazotized 6-aminosaccharin; the resulting azo compound has lost its sweet taste.

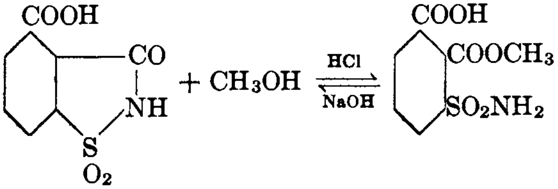
The 5- and 7-methoxysaccharins[119] have been prepared from the

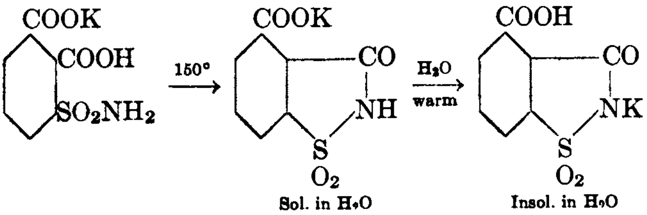


cresyl ethers by the steps indicated. These substances have a bitter taste. 5,6-Dimethoxysaccharin has been obtained from homoveratrole by the oxidation method.[120] Neither this compound nor its sodium salt has a sweet taste.

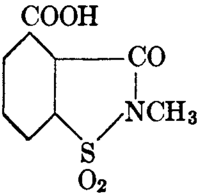


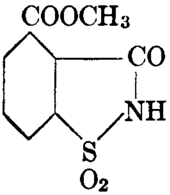
Saccharincarboxylic acids, in particular the 4-isomer,[121] have been much investigated. Oxidation of 1-naphthalenesulfonamide with permanganate gives a mixture of phthalic acid, sulfamidophthalic acid, and saccharin-4-carboxylic acid. The alkaline decomposition of 2,2,3,3-tetrachloro-1,8-naphthasultam-4-quinone also gives this saccharin derivative.[121e] Unlike saccharin itself it is stable toward alkali but hydrolyzes readily to sulfamidophthalic acid with dilute hydrochloric acid. To obtain sulfophthalic acid requires the action of concentrated hydrochloric acid at 150°. The sulfonamide acid is reconverted to the saccharin by heating at its melting point (194°) or upon treatment with concentrated sulfuric acid. The methyl sulfonamidophthalate and the saccharincarboxylic acid are also interconvertible.[121e] It is claimed that the saccharincarboxylic acid yields two distinct potassium salts,[121d] prepared as shown in the equation.





The imide group is more strongly acidic than the carboxyl as shown by comparison of the conductivities of the isomeric methyl derivatives.

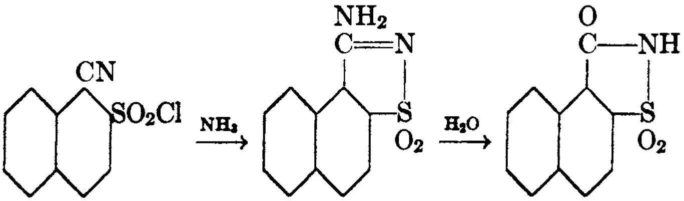




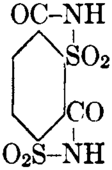
The structure of the N-methyl compound was shown by hydrolysis to methylamine with concentrated hydrochloric acid at 150°. The dimethyl derivative and carboxamide also were prepared.[121d] Fusion of the saccharin-4-carboxylic acid with potassium hydroxide yields the 3-hydroxyphthalic acid.

The saccharin-5- [122] and -6-carboxylic [123] acids have been obtained in the usual manner by oxidation of compounds in which the methyl and sulfonamide groups are adjacent. 7-Methylsaccharin-5-carboxylic acid has been similarly obtained from 4-sulfonamidomesitylenic acid.[124]

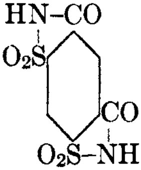
The three possible saccharin derivatives of naphthalene have been prepared; they all are bitter in taste but chemically are much like saccharin. They result from the action of ammonia and then aqueous sodium hydroxide upon the cyanonaphthalenesulfonyl chlorides.[125] The 2,3-compound was prepared from the acid dichloride. The 1,8-compound which is not a true saccharin derivative was also prepared and characterized.



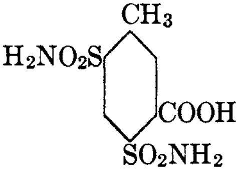
A number of interesting compounds containing two of the heterocyclic nuclei present in saccharin have been synthesized. Of the possible "disaccharins" derived from benzene whose formulas are shown it was one time believed that all had been synthesized [126] but further investigation [127] has indicated that the supposed II is actually II*a* and III is III*a*; there may therefore be some question as to the structures



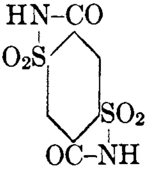
I



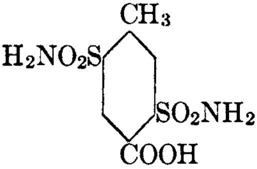
II



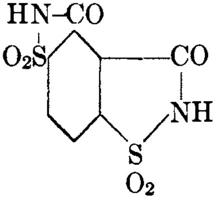
IIa



III



IIIa



IV

of I and IV. None of these substances has a sweet taste. The "di-saccharin" obtained from 4,4′-dimethylbiphenyl[128] was found to be tasteless. Synthesis was effected through oxidation of the 3,3′-disulfonamide with potassium permanganate.

REFERENCES

SULFONAMIDES

1*a*. Northey, *Chem. Rev.*, **27**, 85–197 (1940); additional recent references are: Schnitker, "Sulfanilamide, Sulfopyridine, and Allied Compounds in Infections." Oxford University Press, New York, 1940; Crossley, Northey, and Hultquist, *J. Am. Chem. Soc.*, **62**, 372, 532 (1940); Crossley *et al.*, *ibid.*, **62**, 1415 (1940); Kolloff and Hunter, *ibid.*, **62**, 1646 (1940); Bergeim, Coy, and Lott, *ibid.*, **62**, 1873 (1940); Roblin and Winnek, *ibid.*, **62**, 1999 (1940); Miller, Sprague, Kissinger, and McBurney, *ibid.*, **62**, 1714, 2097, 2099 (1940); Daniels and Iwamoto, *ibid.*, **62**, 3741 (1940); Walker, *J. Chem. Soc.*, 686 (1940); Tatum and Beadle, *Science*, **91**, 458 (1940); James and Fuller, *Biochem. J.*, **34**, 648 (1940); Drozdov and Stavrovskaya, *C.A.*, **34**, 3703 (1940); Ganapathi, *C.A.*, **34**, 6243 (1940); Mangini, *C.A.*, **34**, 7286 (1940); Thorsteinsson, *Dansk. Tids. Farm.*, **16**, 41 (1941); *C.A.*, **35**, 5109 (1941); Platz, Bücking, Smeykal, and Asinger, U. S. pat., 2,242,086, *C.A.*, **35**, 5219 (1941); Ida, Japanese pat., 130,481, *C.A.*, **35**, 5133 (1941); Naegeli, U. S. pat., 2,170,209, *C.A.*, **34**, 1134 (1940); I. G. Farbenind. A.-G., British pat., 466,505, *C.A.*, **31**, 7887 (1937); Basu and Das-Gupta, *C.A.*, **33**, 5852 (1939). *b*. Billeter, *Ber.*, **37**, 692 (1904).

2. Curtius and Lorenzen, *J. prakt. Chem.*, [2] **68**, 176 (1898).

3. Stenhouse, *Ann.*, **140**, 294 (1866); Mares, U. S. pat., 2,236,825, *C.A.*, **36**, 4393 (1941).

4*a*. Halssig, *J. prakt. Chem.*, [2] **56**, 228 (1897). *b*. Whalen and Jones, *J. Am. Chem. Soc.*, **47**, 1353 (1925).

5. Carleson, *Bull. soc. chim.*, [2] **27**, 360 (1877); Remsen and Palmer, *Am. Chem. J.*, **8**, 241 (1886); Hinsberg, *Ann.*, **265**, 180 (1891); Solonina, *Chem. Zentr.*, II, 848 (1897); II, 867 (1899); Schey, *Rec. trav. chim.*, **16**, 181 (1897); Marckwald, *Ber.*, **32**, 3509 (1899); Marckwald and v. Droste-Huelshoff, *Ber.*, **32**, 561 (1899); German pat., 105,870, *Chem. Zentr.*, I, 524 (1900); Schreinemakers, *Rec. trav. chim.*, **16**, 415 (1897); Einhorn and Bull, *Ann.*, **296**, 202 (1897); Willstätter and Lessing, *Ber.*, **33**, 559 (1900); Duden, *Ber.*, **33**, 477 (1900); Marckwald and Chain, German pat., 120,047, *Chem. Zentr.*, I, 1074 (1901); Remsen and Clark, *Am. Chem. J.*, **30**, 281 (1903); Knorr and Rössler, *Ber.*, **36**, 1279 (1903); Fürth, *Monatsh.*, **24**, 278 (1903); v. Braun and Steindorff, *Ber.*, **38**, 3087 (1905); Hinsberg and Kessler, *Ber.*, **38**, 909 (1905); Chattaway, *J. Chem. Soc.*, **87**, 159 (1905); Backer, *Rec. trav. chim.*, **24**, 485 (1905); Johnson and Bailey, *J. Am. Chem. Soc.*, **38**, 2143 (1905); Friedmann, *Beitr. Physiol. Path.*, **8**, 101 (1906); Reverdin, *Ber.*, **42**, 1526 (1909); Wedekind, *Ber.*, **42**, 3941 (1901); Johnson and Guest, *Am. Chem. J.*, **42**, 348 (1909); *ibid.*, **43**, 321 (1910); Pope and Gibson, *J. Chem. Soc.*, **101**, 1703 (1912); Pope and Read, *ibid.*, **101**, 521 (1912); v. Braun, Kruber, and Danziger, *Ber.*, **49**, 2649 (1916); Baxter and Chattaway, *J. Chem. Soc.*, **107**, 1818 (1915);

Demeny, *Rec. trav. chim.*, **48,** 1145 (1929); *ibid.*, **50,** 51 (1931); Schroeter, German pat., 634,687, *C.A.*, **31,** 710 (1937); Walsh and MacDonough, U. S. pat., 1,966,604, *C.A.*, **28,** 5613 (1934). These lists of references on sulfonamide formation cover typical examples but are not exhaustive.

6*a*. Van Romburgh, *Rec. trav. chim.*, **3,** 8 (1884). *b.* Ginsberg, *ibid.*, **36,** 2706 (1903). *c.* Busch and Leefhelm, *J. prakt. Chem.*, [2] **77,** 9 (1908). *d.* Jaeger, *Proc. Acad. Sci. Amsterdam*, **23,** 347 (1920). *e.* Marvel and Smith, *J. Am. Chem. Soc.*, 45, 2696 (1923). *f.* Slotta and Behnisch, *J. prakt. Chem.*, [2] **135,** 225 (1932); Fourneau, Tréfouel, Nitti, and Bovet, *Compt. rend. soc. biol.*, **122,** 258, 652 (1936); Chaplin and Hunter, *J. Chem. Soc.*, 1114 (1937); I. G. Farbenind. A.-G., British pat., 511,845, *C.A.*, **34,** 7543 (1940).

7. Marckwald and Frobenius, *Ber.*, **34,** 3547 (1901); Bewad, *J. prakt. Chem.*, [2] **63,** 197 (1901); *Ber.*, 40, 3076 (1907); Solonina, *Chem. Zentr.*, II, 888 (1898); Beckmann and Fellrath, *Ann.*, **273,** 19 (1893); Walker, *J. Chem. Soc.*, 686 (1940).

8. Howard and Marckwald, *Ber.*, **32,** 2032 (1899); Hinsberg, *Ann.*, **265,** 180 (1891); Schotten and Schlömann, *Ber.*, **24,** 3689 (1891); Franchimont and Taverne, *Rec. trav. chim.*, **15,** 72 (1896); v. Braun and Sobecki, *Ber.*, **44,** 2160 (1911); Willstätter and Jaquet, *Ber.*, **51,** 779 (1918); v. Braun and Bartsch, *Ber.*, **45,** 3384 (1912); Gabriel, *Ber.*, **43,** 360 (1910).

9. Hinsberg and Strupler, *Ann.*, **287,** 221 (1895); Solonina, *J. Russ. Phys.-Chem. Soc.*, **28,** 562 (1896); *Chem. Fabr. Schering*, German pat., 70,055, *Frdl.*, **3,** 951; Howard and Marckwald, *Ber.*, **32,** 2032 (1899); Esch and Marckwald, *Ber.*, **33,** 762 (1900); v. Braun, *Ber.*, **37,** 3588 (1904); v. Braun and Müller, *Ber.*, **38,** 2205 (1905); **39,** 4114 (1906); v. Braun, *Ber.*, **42,** 4554 (1909); Amundsen and Longley, *J. Am. Chem. Soc.*, **62,** 2811 (1940). This last reference summarizes earlier work on ethylenediamine derivatives.

10. Biffi, *Ann.*, **91,** 107 (1854); Gericke, *Ann.*, **100,** 217 (1856); Ascher and Meyer, *Ber.*, **4,** 326 (1871); Nölting, *Ber.*, **8,** 597 (1875); Müller and Wiesinger, *Ber.*, **12,** 1348 (1879); Wallach, *Ann.*, **214,** 221 (1882); Remsen and Palmer, *Am. Chem. J.*, 8, **242** (1886); Brugnatelli, *J. prakt. Chem.* [2] **47,** 368 (1893); Otto, *ibid.*, [2] **47,** 369 (1893); Tröger and Uhlmann, *ibid.*, **51,** 437 (1895); Reverdin and Crépieux, *Bull. soc. chim.*, [3] **25,** 1048 (1876); *Ber.*, **34,** 3000 (1901); Ginzberg, *Ber.*, **36,** 2706 (1903); Chattaway, *J. Chem. Soc.*, **85,** 1187 (1904); Ullmann and Gross, *Ber.*, **43,** 2700 (1910).

11*a*. *Halogen derivatives:* Wallach and Huth, *Ber.*, 9, **426** (1876); Ullmann and Gilli, *Ann.*, **332,** 60 (1904); v. Braun, *Ber.*, **37,** 2811 (1904); Raper, Thompson, and Cohen, *J. Chem. Soc.*, **85,** 372 (1904); Chattaway, *J. Chem. Soc.*, **85,** 1184 (1904); A.-G. für Anilinfabrik, German pat., 157,859, *Chem. Zentr.*, I, 415 (1905); German pat., 164,130, *ibid.*, II, 1476 (1905); v. Braun, *Ber.*, **40,** 3926 (1907); Baxter and Chattaway, *J. Chem. Soc.*, **107,** 1820 (1915); Chattaway and Clemo, *ibid.*, **109,** 104 (1916); Halberkann, *Ber.*, **54,** 1846 (1921); Marvel and Smith, *J. Am. Chem. Soc.*, **45,** 2696 (1923); Marvel, Kingsbury, and Smith, *ibid.*, **47,** 166 (1925); Jones, *J. Chem. Soc.*, **1414** (1938). *b. Nitro derivatives:* Lellmann, *Ann.*, **221,** 16 (1883); *Ber.*, 16, **594** (1883); A.-G. für Anilinfabrik, German pat., 135,016, *Chem. Zentr.*, II, 1166 (1902); Morgan and Micklethwait, *J.*

Chem. Soc., **87**, 84, 1303 (1905); **89**, 1292 (1906); Opolski, *Ber.*, **40**, 3530 (1907); Bell and Robinson, *J. Chem. Soc.*, 1127 (1927). *c. Aminophenols and their ethers:* Hinsberg, *Ann.*, **265**, 178 (1890); Tröger and Uhlmann, *J. prakt. Chem.*, [2] **51**, 437 (1895); Diepolder, *Ber.*, **32**, 3517 (1899); Reverdin and Crépieux, *Ber.*, **34**, 3002 (1901); Chem. Fabr. Sandoz, German pat., 128,815, *Chem. Zentr.*, I, 551 (1902); A.-G. für Anilinfabrik, German pat., 157,859, *ibid.*, I, 415 (1905); v. Braun, *Ber.*, **37**, 2811 (1904); Reverdin, *Ber.*, **42**, 1523 (1909); ref. 6*e*; Raiford and Grasz, *J. Am. Chem. Soc.*, **53**, 3420 (1931).

12. Wolkowa, *Z. Chem.*, 324 (1870); Wallace and Huth, *Ber.*, **9**, 426 (1876); Müller, *Ber.*, **12**, 1348 (1879); Lellmann, *Ann.*, **221**, 16 (1883); Hinsberg, *Ann.*, **265**, 178 (1891); Beckmann and Fellrath, *Ann.*, **273**, 13 (1893); Rabaut, *Bull. soc. chim.*, [3] **15**, 1035 (1896); A.-G. für Anilinfabrik, German pat., 135,016, *Chem. Zentr.*, II, 1166 (1902); German pat., 157,859, *ibid.*, I, 415 (1905); German pat., 164,130, *ibid.*, II, 1476 (1905); Reverdin and Crépieux, *Ber.*, **35**, 1440 (1902); Chattaway, *J. Chem. Soc.*, **85**, 1184 (1904); Raper, Thompson, and Cohen, *ibid.*, **85**, 372 (1904); Morgan and Micklethwait, *ibid.*, **87**, 926 (1905); **89**, 1292 (1906); Hinsberg and Kessler, *Ber.*, **38**, 911 (1905); Ullmann and Gross, *Ber.*, **43**, 2696 (1910); Reverdin and de Luc, *Ber.*, **43**, 3463 (1910); Witt and Uerményi, *Ber.*, **46**, 296 (1913); Witt and Truttwin, *Ber.*, **47**, 2792 (1914); Baxter and Chattaway, *J. Chem. Soc.*, **107**, 1820 (1915); Raiford and Lankelma, *J. Am. Chem. Soc.*, **47**, 1122 (1925); Raiford and Grasz, *ibid.*, **53**, 3420 (1921); Bader and Nightengale, U. S. pat., 1,433,925, *C.A.*, **17**, 402 (1923).
13. Hinsberg, *Ann.*, **265**, 178 (1891); Beckmann and Fellrath, *Ann.*, **273**, 13 (1893); Otto, *J. prakt. Chem.*, [2] **48**, 368 (1893); Busch, *ibid.*, [2] **51**, 263 (1895); Apitzsch, *Ber.*, **33**, 3524 (1900); Ginzberg, *Ber.*, **36**, 2706 (1903); v. Braun, *Ber.*, **42**, 2224 (1909); Witt and Uerményi, *Ber.*, **46**, 296 (1913); Halberkann, *Ber.*, **54**, 1835 (1921); ref. 6*e;* Marvel, Kingsbury, and Smith, *J. Am. Chem. Soc.*, **47**, 166 (1925); Hickinbottom, *J. Chem. Soc.*, 1119 (1937); Mumm and Möller, *Ber.*, **70B**, 2214 (1937); Emerson and Robb, *J. Am. Chem. Soc.*, **61**, 3145 (1939).
14. Wallach, *Ann.*, **214**, 221 (1882); Reverdin and Crépieux, *Ber.*, **35**, 1441 (1902); Halberkann, *Ber.*, **55B**, 3079 (1922).
15. Bell, Kenyon, and Robinson, *J. Chem. Soc.*, 1239 (1926); Bell, *ibid.*, 2770 (1928); 1071 (1930).
16. Witt and Schmitt, *Ber.*, **27**, 2370 (1894); Wheeler, Smith, and Warren, *Am. Chem. J.*, **19**, 764 (1897); Raper, Thompson, and Cohen, *J. Chem. Soc.*, **85**, 372 (1904); A.-G. für Anilinfabrik, German pat., 157,859, *Chem. Zentr.*, I, 415 (1905); German pat., 164,130, *ibid.*, II, 1476 (1905); Morgan and Micklethwait, *J. Chem. Soc.*, **89**, 8 (1906); Morgan and Godden, *ibid.*, **97**, 1714 (1910); Le Sueur, *ibid.*, **99**, 833 (1911); ref. 6*e;* Marvel, Kingsbury, and Smith, *J. Am. Chem. Soc.*, **47**, 166 (1925); Reilly, Drumm, and O'Sullivan, *J. Soc. Chem. Ind.*, **46**, 436 (1927).
17. Ihrfelt, *Ber.*, **22R**, 692 (1889); Hedin, *Ber.*, **23**, 3198 (1890); Pechmann, *Ann.*, **264**, 289 (1891); Fischer, *Ber.*, **33**, 2382 (1900); Fischer and Mouneyrat, *Ber.*, **33**, 2389 (1900); Fischer, *Ber.*, **34**, 448 (1901); Fischer and Bergell, *Ber.*, **35**, 3780 (1902); Abderhalden, *Z. physiol. Chem.*, **38**, 558 (1903); Ehrlich, *Ber.*, **37**, 1828 (1904); Leuchs, *Ber.*, **38**, 1941 (1905); Bouveault and Locquin, *Compt. rend.*, **141**, 116 (1905); *Bull. soc. chim.*,

[3] **35**, 969 (1906); Johnson and McCollum, *Am. Chem. J.*, **35**, 58 (1906); Riesser, *Z. physiol. Chem.*, **49**, 240 (1906); Locquin, *Bull. soc. chim.*, [4] **1**, 606 (1907); Braun, *Ber.*, **40**, 1839 (1907); Abderhalden and Kempe, *Z. physiol. Chem.*, **52**, 217 (1907); Forster and Fierz, *J. Chem. Soc.*, **93**, 1864 (1908); Friedmann, *Beitr. Chem. Physiol. Path.*, **11**, 161 (1908); Bergell and Fiegl, *Z. physiol. Chem.*, **55**, 176 (1908); Ellinger and Flamand, *ibid.*, **55**, 22 (1908); Königs and Mylo, *Ber.*, **41**, 4433 (1908); Bergell and Wülfing, *Z. physiol. Chem.*, **64**, 361 (1910); Bergell and Brugsch, *ibid.*, **67**, 100 (1910); Fischer and Scheibler, *Ann.*, **383**, 343 (1911); Kondo, *Biochem. Z.*, **38**, 411 (1912); Pope and Gibson, *J. Chem. Soc.*, **101**, 945 (1912); Abderhalden and Weil, *Z. physiol. Chem.*, **88**, 273 (1913); Fischer and Bergmann, *Ann.*, **398**, 105 (1913); Löb, *Biochem. Z.*, **51**, 123 (1913); **60**, 169 (1914); Le Sueur and Withers, *J. Chem. Soc.*, **105**, 2818 (1914); Knoop and Landmann, *Z. physiol. Chem.*, **89**, 159 (1914); Gibson and Simonsen, *J. Chem. Soc.*, **107**, 799 (1915); Fischer and Lipschitz, *Ber.*, **48**, 362 (1915); Fischer and v. Mechel, *Ber.*, **49**, 1361 (1916); Abderhalden and Wybert, *Ber.*, **49**, 2469 (1916); Kossel and Edlbacher, *Z. physiol. Chem.*, **94**, 275 (1915); Bergell, *ibid.*, **97**, 260 (1916); **99**, 158 (1917); Dakin, *Biochem. J.*, **12**, 311 (1918); Thomas and Schotte, *Z. physiol. Chem.*, **104**, 148 (1919); Dubsky and Blumer, *Ber.*, **52**, 218 (1919); Thomas and Goerne, *Z. physiol. Chem.*, **104**, 82 (1919); Bergell, *ibid.*, **104**, 185 (1919); Oseki, *J. Tokyo Chem. Soc.*, **41**, 8 (1920); *C.A.*, **14**, 2780 (1920); Colles and Gibson, *J. Chem. Soc.*, **125**, 2505 (1924); Freudenberg and Noë, *Ber.*, **58B**, 2407 (1925); Karrer and Kehl, *Helv. Chim. Acta*, **13**, 57 (1930); Karrer and van der Sluys Veer, *ibid.*, **15**, 750 (1932); McChesney and Swann, *J. Am. Chem. Soc.*, **59**, 1116 (1937).

18. Fischer and Bergell, *Ber.*, **35**, 3780 (1902); **36**, 2106, 2594 (1903); Abderhalden and Wybert, *Ber.*, **49**, 2470 (1916); Hopwood and Weizmann, *J. Chem. Soc.*, **99**, 573, 1579 (1911).

19. Franke, *J. prakt. Chem.*, [2] **44**, 419 (1891); Einhorn and Faust, *Ber.*, **27**, 1883 (1894); Zahn, *J. prakt. Chem.*, [2] **61**, 540 (1900); Vorländer, *Ber.*, **35**, 1685 (1902); Ullmann and Bleier, *Ber.*, **35**, 4274 (1902); Bogert and Beans, *J. Am. Chem. Soc.*, **26**, 478 (1904); Pawlewski, *Ber.*, **38**, 1683 (1905); Schroeter, *Ber.*, **40**, 1618 (1907); Schroeter and Eisleb, *Ann.*, **367**, 104 (1907).

20*a*. *Aliphatic amino ketones:* Gabriel and Posner, *Ber.*, **27**, 1038 (1894); Künne, *Ber.*, **28**, 2043 (1895); Kolshorn, *Ber.*, **37**, 2478 (1904); Gabriel, *Ber.*, **43**, 357 (1910); Solonina, *Chem. Zentr.*, II, 868 (1899). *b. Aromatic amino ketones:* Chattaway, *J. Chem. Soc.*, **85**, 389 (1904); Elson, Gibson, and Johnson, *ibid.*, 1128 (1930).

21*a*. Márques, *Bol. soc. quim. Peru*, **6**, No. 1, 19 (1940); *C.A.*, **34**, 5422 (1940). *b.* Steinkopf, *J. prakt. Chem.*, **117**, 1 (1927). *c.* Simons, U. S. pat., 2,237,372, *C.A.*, 4398 (1941). *d.* I. G. Farbenind. A.-G., British pat., 482,524, *C.A.*, **32**, 6670 (1938).

22. *N-Alkyl and N,N-Dialkylamides:* Van Romburgh, *Rec. trav. chim.*, **3**, 8 (1884); Hinsberg, *Ann.*, **265**, 180 (1891); Marckwald and Droste-Huelshoff, *Ber.*, **31**, 3262 (1898); *Ber.*, **32**, 561 (1899); German pat., 105,870, *Chem. Zentr.*, I, **524** (1900); Marckwald, *Ber.*, **32**, 3509 (1899); Marckwald and Frobenius, *Ber.*, **34**, 3547 (1901); Marckwald and Chain, German pat., 120,047, *Chem. Zentr.*, I, 1074 (1901); *Ber.*, **34**, 1158 (1901);

Hantzsch and Voegelen, *Ber.*, **34**, 3162 (1901); Ginzberg, *Ber.*, **36**, 2706 (1903); Mulder, *Rec. trav. chim.*, **25**, 104 (1906); Wedekind, *Ber.*, **42**, 3941 (1909); Johnson and Guest, *Am. Chem. J.*, **43**, 321 (1910); Pope and Read, *J. Chem. Soc.*, **101**, 521 (1912); Braun, Kruber, and Danziger, *Ber.*, **49**, 2649 (1916); Müller and Sauerwald, *Monatsh.*, **48**, 155, 521, 727 (1927); Carothers, Bickford, and Hurwitz, *J. Am. Chem. Soc.*, **49**, 2908 (1927); Slotta and Behnisch, *J. prakt. Chem.*, **135**, 225 (1932); Gofferje and Hopff, German pat., 637,771, *C.A.*, **31**, 2614 (1937). *N-Alkyl-N-arylamides:* Lellmann, *Ber.*, **16**, 594 (1883); Ullmann, *Ann.*, **327**, 110 (1903); Ullmann and Gilli, *Ann.*, **332**, 60 (1904); Hinsberg and Kessler, *Ber.*, **38**, 911 (1905); Morgan and Micklethwait, *J. Chem. Soc.*, **87**, 84 (1905); **89**, 8 (1906); **91**, 1516 (1907); Pschorr and Karo, *Ber.*, **39**, 3141 (1906); Opolski, *Ber.*, **40**, 3530 (1907); *Chem. Zentr.*, II, 879 (1910); Morgan and Micklethwait, *J. Chem. Soc.*, **101**, 143 (1912); Bell and Robinson, *ibid.*, 1127 (1927); Reilly, Drumm, and O'Sullivan, *J. Soc. Chem. Ind.*, **46**, 436 (1927); Bell, *J. Chem. Soc.*, 2770 (1928); Young, *J. Am. Chem. Soc.*, **56**, 2167, 2783 (1934); Gillespie, *ibid.*, **55**, 2740 (1934); Young, *ibid.*, **57**, 773 (1935); Keimatsu, Sugawa, and Lee, *J. Pharm. Soc. Japan*, **57**, 294 (1937); *C.A.*, **31**, 5353 (1937).

23. Lukeš and Přeučil, *Collection Czechoslov. Chem. Commun.*, **10**, 384 (1938); *C.A.*, **33**, 983 (1939).
24. Sakai and Yamamoto, *J. Pharm. Soc. Japan*, **58**, 683 (1938); *C.A.*, **34**, 86 (1940).
25. Bayer and Co., German pat., 346,810, *C.A.*, **17**, 1249 (1923).
26. Bennett, Dodd, and Sprent, British pat., 336,512, *C.A.*, **25**, 1841 (1931).
27. Johnson and McCollum, *Am. Chem. J.*, **36**, 58 (1906); Alpern and Weizmann, *J. Chem. Soc.*, **99**, 87 (1911); Fischer and Bergmann, *Ann.*, **398**, 105 (1913); Fischer and Lipschitz, *Ber.*, **48**, 362 (1915); Thomas and Goerne, *Z. physiol. Chem.*, **104**, 82 (1919); Thomas and Schotte, *ibid.*, **104**, 148 (1919); Schroeter, *Z. angew. Chem.*, **39**, 1460 (1926); Mills and Elliot, *J. Chem. Soc.*, 1291 (1928).
28. Peacock and Gwan, *J. Chem. Soc.*, 1468 (1937); Soc. pour l'ind. chim. à Bâle, French pat., 799,220, *C.A.*, **30**, 7726 (1936).
29*a*. Ohle and Haeseler, *Ber.*, **69B**, 2324 (1936). *b*. Moss, British pat., 483,087, *C.A.*, **32**, 7167 (1938); British pat., 506,999, *C.A.*, **34**, 546 (1940).
30. Ohle, Friedeberg, and Haeseler, *Ber.*, **69B**, 2311 (1936).
31. Bren, U. S. pat., 2,071,917, *C.A.*, **31**, 2615 (1937).
32*a*. Hinsberg and Strupler, *Ann.*, **265**, 178 (1895). *b*. Marckwald and Droste-Huelshoff, *Ber.*, **31**, 3261 (1898). *c*. Adams and Cairns, *J. Am. Chem. Soc.*, **61**, 2464 (1939).
33. Yanbikov and Dem'yanov, *J. Gen. Chem.* (*U.S.S.R.*), 8, 1545 (1938); *C.A.*, **33**, 4583 (1939).
34. Hinsberg and Kessler, *Ann.*, **340**, 119 (1905).
35. Müller and Sauerwald, *Monatsh.*, **48**, 155 (1927).
36. Müller and Sauerwald, *ibid.*, **48**, 521, 727 (1927).
37. Litherland and Mann, *J. Chem. Soc.*, 1588 (1938).
38. Ullmann and Glenck, *Ber.*, **49**, 2497 (1916); A.-G. für Anilinfabrik, German pat., 293,100, *C.A.*, **11**, 2581 (1917); Locher and Fierz, *Helv. Chim. Acta*, **10**, 642 (1927); Ruggli and Merz, *ibid.*, **12**, 71 (1929); Bradley, Loveluck, and Thomson, U. S. pat., 1,863,265, *C.A.*, **26**, 4063 (1932); I. G.

Farbenind. A.-G., British pat., 502,173, *C.A.*, **33**, 6529 (1939); Soc. pour l'ind. chim. à Bâle, French pat., 811,479, *C.A.*, **32**, 591 (1938).

39. Kereszty and Wolf, French pat., 837,468, *C.A.*, **33**, 7315 (1939).
40. Lellmann, *Ann.*, **221**, 17 (1883); Willstätter and Kalb, *Ber.*, **37**, 3772 (1904); Morgan and Micklethwait, *J. Chem. Soc.*, **87**, 80, 929, 1303 (1905); **89**, 8, 1296 (1906); **91**, 364 (1907); **101**, 143 (1912); A.-G. für Anilinfabrik, German pat., 160,710, *Chem. Zentr.*, I, 1677 (1905); Morgan and Hird, *J. Chem. Soc.*, **91**, 1508 (1907); Morgan and Grist, *ibid.*, **119**, 602 (1921); Morgan, U. S. pat., 1,442,818, *C.A.*, **17**, 1242 (1923).
41. Schmidt and Helmert, German pat., 530,823, *C.A.*, **26**, 1618 (1932).
42. Remsen and Clark, *Am. Chem. J.*, **30**, 280 (1903); Fahlberg and List, *Ber.*, 20, 1599 (1887); Eckenroth and Koerppen, *Ber.*, **30**, 1268 (1897).
43. Sachs, Wolff, and Ludwig, *Ber.*, **37**, 3258 (1904); Sachs and Ludwig, *Ber.*, 37, 389 (1904).
44. Ador and Meyer, *Ann.*, **159**, 11 (1871).
45. Claësson and Wallin, *Ber.*, **12**, 1853 (1879).
46. Von Auwers, *Z. physik. Chem.*, **23**, 449 (1897); Chaplin and Hunter, *J. Chem. Soc.*, 1114 (1937).
47. Le Fèvre and Vine, *ibid.*, 1790 (1938).
48. Angus, Leckie, and Williams, *Trans. Faraday Soc.*, **34**, 793 (1938).
49. Freymann and Rumpf, *Compt. rend.*, **201**, 606 (1935).
50. Baroni, *C.A.*, **34**, 7871 (1940).
51. Halla and Kratky, *Z. Krist.*, **71**, 263 (1929).
52. Young, Keith, and Honess, *Z. Krist.*, **92**, 216, 395 (1935); **93**, 107 (1936).
53. Timmermans, *Bull. soc. chim. Belg.*, **44**, 17 (1935).
54a. Hantzsch and Voegelen, *Ber.*, **34**, 3142 (1901). *b.* Marckwald and Droste-Huelshoff, *Ber.*, **31**, 3261 (1898).
55. Heller and Fleischhans, *J. prakt. Chem.*, [2] **123**, 146 (1929).
56. Hinsberg, *Ber.*, **23**, 2962 (1890); *Ann.*, **265**, 180 (1891).
57. Solonina, *J. Russ. Phys.-Chem. Soc.*, **29**, **404** (1897); **31**, 640 (1899); *Chem. Zentr.*, II, 848 (1897); II, 867 (1899).
58. Marckwald, *Ber.*, **32**, 3512 (1899).
59. Duden, *Ber.*, **33**, 478 (1900).
60. Carothers and Jones, *J. Am. Chem. Soc.*, **47**, 3054 (1925); Carothers, Bickford, and Hurwitz, *ibid.*, **49**, 2913 (1927).
61. Marvel and Smith, *ibid.*, **45**, 2696 (1923).
62. Demeny, *Rec. trav. chim.*, **48**, 1145 (1929).
63. Goslich, *Ann.*, **180**, 106 (1876); Bässmann, *Ann.*, **191**, 233 (1878); Schotten and Schlömann, *Ber.*, **24**, 3687 (1891); Johnson and Ambler, *J. Am. Chem. Soc.*, **36**, 373 (1914).
64. Schreiber and Shriner, *ibid.*, **56**, 1618 (1934); Shriner, Oppenlander, and Schreiber, *J. Org. Chem.*, **4**, 588 (1939).
65. Marvel, Helfrick, and Belsley, *J. Am. Chem. Soc.*, **51**, 1272 (1929).
66. Schroeter and Eisleb, *Ann.*, **367**, 101 (1909).
67. Reverdin, *Helv. Chim. Acta*, **8**, **602** (1925).
68. Witt and Uerményi, *Ber.*, **46**, **296** (1913); Witt and Truttwin, *Ber.*, **47**, **2786** (1914). See also Chapter VII on sulfones.
69. Halberkann, *Ber.*, **54B**, 1665 (1921).
70. Leitch and Co., and Everest, British pat., 257,979, *C.A.*, **21**, 3058 (1927).
71. Halberkann, *Ber.*, **55B**, 3074 (1922).

72. Marckwald and Droste-Huelshoff, German pat., 105,870, *Chem. Zentr.*, I, 524 (1900); Van Romburgh, *Rec. trav. chim.*, **3**, 8 (1884).

73. Limpricht and Hansen, *Ber.*, **18**, 2174 (1885); Limpricht and Jaworowicz, *Ber.*, **18**, 2173 (1885); Schroeter, German pat., 034,687, *C.A.*, **31**, 710 (1937).

74. Shuloff, Pollak, and Riesz with co-workers, *Ber.*, **62B**, 1846 (1929).

75. Schroeter, *Z. angew. Chem.*, **39**, 1460 (1926).

76. Abderhalden and Riesz, German pat., 539,403, *C.A.*, **26**, 1619 (1932); Nölting, *Ber.*, 8, 598 (1875).

77. Fischer, *Ber.*, **48**, 93 (1915); Miescher and Billeter, *Helv. Chim. Acta*, **22**, 601 (1939); Thomas, German pat., 497,097, *C.A.*, **24**, 3516 (1930).

78. A. W. Ruddy, this laboratory, unpublished results.

79*a*. Michler and Salathé, *Ber.*, **12**, 1789 (1879). *b*. Harington and Moggridge, *J. Chem. Soc.*, 706 (1940).

80. Heffter, *Ann.*, **221**, 203 (1883); see also Reverdin and Crépieux, *Ber.*, **34**, 2993 (1901).

81. Rouiller, *Am. Chem. J.*, **47**, 488 (1912).

82. Pezold, Schreiber, and Shriner, *J. Am. Chem. Soc.*, **56**, 696 (1934); Schreiber and Shriner, *ibid.*, **66**, 114 (1934).

83. Fenton and Ingold, *J. Chem. Soc.*, 3295 (1928).

84. Holmes and Ingold, *ibid.*, 1305 (1926).

85a. Raiford and Lankelma, *J. Am. Chem. Soc.*, **47**, 1122 (1925); see also Raiford and Grosz, *ibid.*, **53**, 3420 (1931). *b*. Nelles, Tietze, and Bayer, German pat., 695,331, *C.A.*, **35**, 5128 (1941).

86. Magnus-Levy, *Ber.*, **26**, 2148 (1893).

87. Hug, *Bull. soc. chim.*, [5] **1**, 990 (1934).

88. McMaster, *J. Am. Chem. Soc.*, **56**, 204 (1934).

89. Wood and Battye, *J. Soc. Chem. Ind.*, **52**, 346 (1933).

90. Farbwerke vorm. Meister, Lucius, and Brüning, German pat., 359,676; *Chem. Zentr.*, II, 340 (1923); German pat., 369,644, *ibid.*, II, 922 (1923); German pat., 466,519, *ibid.*, I, 3143 (1929); Rispler, Luthy, and Schilling, British pat., 349,956, *C.A.*, **26**, 5392 (1932); Moss and White, U. S. pat., 1,907,554, *C.A.*, **27**, 3629 (1933); Canadian pat., 313,858, *C.A.*, **25**, 5305 (1931); U. S. pat., 1,908,159, *C.A.*, **27**, 3837 (1933); Seymour, U. S. pat., 2,022,389, *C.A.*, **30**, 788 (1936); Bender, U. S. pat., 2,064,876, *C.A.*, **31**, 787 (1937); Fahlberg-List A.-G. Chem. Fabriken, French pat., 806,558, *C.A.*, **31**, 4749 (1937); Hahn and Memminger, U. S. pat., 2,130,342, *C.A.*, **32**, 9498 (1938); Russell and Copenhauer, U. S. pat., 2,191,943, *C.A.*, **34**, 4607 (1940).

91. For a patent review see Albrecht, *Rev. gén. mat. plastiques*, **15**, 135 (1939).

92. Walter, *Trans. Faraday Soc.*, **32**, 402 (1936); Walter and Glück, *Kolloid-Beihefte*, **37**, 343 (1933).

93. Walter and Storfer, *ibid.*, **37**, 378 (1933); Walter, U. S. pat., 2,072,971, *C.A.*, **31**, 3177 (1937).

94. Walter and Lutwak, *Kolloid-Beihefte*, **37**, 385 (1933).

95. Moss and White, Canadian pat., 303,697, *C.A.*, **24**, 5518 (1930).

96. Knoevenagel and Lebach, *Ber.*, **37**, 4100 (1904).

97. Ullmann and Kertész, *Ber.*, **62B**, 545 (1919).

98. Hinsberg, *Ber.*, **27**, 598 (1884).

99. Dutt, Whitehead, and Wormall, *J. Chem. Soc.*, **119**, 2088 (1921).

100. Hantzsch and Singer, *Ber.*, **30**, 312 (1897).
101. Key and Dutt, *J. Chem. Soc.*, 2035 (1928).
102. Dutt, *ibid.*, **125**, 1463 (1924).
103. Battegay and Schneider, *Chimie & industrie*, Special No., 497 (February, 1929).
104. Morgan and Godden, *J. Chem. Soc.*, **97**, 1711 (1910).
105. Gerhardt and Chiozza, *Ann. chim.*, [3] 46, 145 (1856); *Ann.*, **87**, 300 (1853).
106. Wolkow, *Z. Chem.*, 479 (1870); 422 (1871); *J. Russ. Phys.-Chem. Soc.*, **3**, 244 (1871); Kimberly, *Ann.*, **114**, 138 (1860); Nölting, *Ber.*, **8**, 598 (1875); Van Charante, *Rec. trav. chim.*, **32**, 94 (1913); Bückel, German pat., 281,363, *Frdl.*, **12**, 89.
107. Carswell and Gump, U. S. pat., 1,916,604, *C.A.*, **27**, 4541 (1933).
108. Evans and Dehn, *J. Am. Chem. Soc.*, **52**, 2531 (1930).
109. Evans and Dehn, *ibid.*, **51**, 3652 (1929).
110. Amundsen and Pollard, *ibid.*, **57**, 1536 (1935).
111. Wertheim, *ibid.*, **53**, 1172 (1931).
112. Wertheim, *ibid.*, 56, 971 (1934).
113. Schroeter and Eisleb, *Ann.*, **367**, 107 (1909).
114. Höchster Farbwerke, German pat., 125,390, *Chem. Zentr.*, II, 1185 (1901).
115. Suzuki, *J. Coll. Sci. Imp. Univ. Tokyo*, **25**, article 15; *C.A.*, **3**, 644 (1909).
116. Bell, *J. Chem. Soc.*, 2787 (1929); 1071 (1930); 609 (1931); Bell and Cohen, *ibid.*, 1290 (1933).
117. Hinsberg, *Ber.*, **25**, 1093 (1892).

118*a*. Solonina, *Chem. Zentr.*, II, 848 (1897); II, 867 (1899). *b*. Van Romburgh, *Rec. trav. chim.*, **3**, 11 (1884). *c*. De Jong, *Chem. Weekblad*, **20**, 259 (1923).

119. Backer, *Rec. trav. chim.*, **24**, 485 (1905).
120. Jaeger, *Proc. Acad. Sci. Amsterdam*, **23**, 347 (1920).
121. Bungenberg De Jong, *Verslag. Akad. Wetenschappen Amsterdam*, **32**, 14 (1923); *C.A.*, **18**, 1482 (1924).
122. Van Dorp, *Rec. trav. chim.*, **28**, 68 (1909).
123. Wallin, *Acta Universitatis Lundensis*, **28**, part 2, paper *3*, p. 20.
124. Schuloff, Pollak, and Riesz with co-workers, *Ber.*, **62B**, 1846 (1929).
125. Orton and Bradfield, *J. Chem. Soc.*, 986 (1927).
126. Jones, *ibid.*, 1231 (1936).
127. Battegay and Besanzon, *Chimie & industrie*, Special No., 495 (February, 1929); *C.A.*, **23**, 4203 (1929).
128. Bell, *J. Chem. Soc.*, 2338 (1931).
129. Everest, British pat., 261,459, *C.A.*, **21**, 3369 (1927).
130. Shriner, Goebel, and Marvel, *J. Am. Chem. Soc.*, **54**, 2470 (1932).
131. Witt and Schmidt, *Ber.*, **27**, 2360 (1894); Battegay and Schneider, *Chimie & industrie*, Special No., 497 (1929).
132. Morgan and Grist, *J. Chem. Soc.*, **119**, 602 (1921); Morgan, British pat., 160,853, *C.A.*, **15**, 2445 (1921).
133. Hinsberg, *Ber.*, **27**, 598 (1894).
134. Bayer and Co., German pat., 224,388, *Frdl.*, **10**, 1216.
135. Hinsberg, *Ber.*, **25**, 1093 (1892).
136. Mathews, *J. Phys. Chem.*, **24**, 108 (1920).
137. Andersen, U. S. pat., 2,135,553, *C.A.*, **33**, 1448 (1939).
138. v. Braun, *Ber.*, **37**, 2811 (1904).

139. Hebenstreit, *J. prakt. Chem.*, [2] **41**, 111 (1890).

140. Graebe and Kraft, *Ber.*, **39**, 2509 (1906).

141. Wichelhaus, *Ber.*, **2**, 502 (1869); Michaelis, *Ann.*, **326**, 135 (1902).

142. Remsen and Rich, *Am. Chem. J.*, **11**, 348 (1889).

143. Remsen, Hartman, and Muckenfuss, *Am. Chem. J.*, **18**, 150 (1896).

144. Remsen, Hartman, and Muckenfuss, *ibid.*, **18**, 154 (1896).

145. Braun and Weissbach, *Ber.*, **63B**, 2836 (1930).

146. Backeberg, *J. Chem. Soc.*, 618 (1933).

147*a*. Meybeck, *Ann. chim.*, **17**, 129 (1932). *b*. Battegay, Denivelle, and Meybeck, *Compt. rend.*, **193**, 1195 (1931). *c*. Dermer and Fernelius, *Z. anorg. allgem. Chem.*, **221**, 83 (1934).

148. Billeter, *Ber.*, **36**, 3220 (1903).

149. Billeter, *Ber.*, **37**, 695 (1904).

150. Wood, *Nature*, **136**, 837 (1935).

151. Nakaseko, *Am. Chem. J.*, **47**, 429 (1912); Waters, *ibid.*, **47**, 333 (1912); Stoddard, *ibid.*, **47**, 1 (1912); Nowell, *ibid.*, **48**, 223 (1913); Chamberlain, *ibid.*, **47**, 318 (1912).

152. Gilman and Vernon, *Rec. trav. chim.*, **48**, 745 (1929).

153. Bettzieche, Menger, and Wolf, *Z. physiol. Chem.*, **160**, 270 (1926).

154. Tozer and Smiles, *J. Chem. Soc.*, 2052 (1938).

155. Flaschenträger, Bernhard, Löwenberg, and Schläpfer, *Z. physiol. Chem.*, **225**, 157 (1934).

156. Vargha, *Magyar Biol. Kutatóintezet Munkái*, **11**, 372 (1939); *C.A.*, **34**, 3703 (1940).

157. Behnisch, Klarer, and Mietzsch, U. S. pat., 2,169,971, *C.A.*, **34**, 1134 (1940).

158. Schering Kahlbaum, A.-G., British pat., 502,558, *C.A.*, **33**, 6878 (1939).

159. Tozer and Smiles, *J. Chem. Soc.*, 2052 (1938).

160. Kuhn and Birkhofer, *Ber.*, **71B**, 621 (1938); Meyer and Schreiber, U. S. pat., 2,141,843, *C.A.*, **33**, 2656 (1939); Schering A.-G., French pat., 842,726, *C.A.*, **34**, 5857 (1940).

161. Kumler, *J. Am. Chem. Soc.*, **62**, 2560 (1940).

162. Stern and Taub, *J. Am. Pharm. Assoc.*, **28**, 1032 (1939).

163. Seikel, *J. Am. Chem. Soc.*, **62**, 1214 (1940).

164. James, *Biochem. J.*, **34**, 640 (1940); Carrara and Mongoni, *Chimica Industria (Italy)*, **22**, 215 (1940); *C.A.*, **34**, 7006 (1940).

165. James, *Biochem. J.*, **34**, 636 (1940).

166. Rosenthal and Bauer, *Science*, **91**, 509 (1940).

167. Scudi, *J. Am. Chem. Soc.*, **59**, 1480 (1937).

168*a*. Kermack, Spragg, and Tebrich, *J. Chem. Soc.*, 608 (1939). *b*. I. G. Farbenind. A.-G., French pat., 845,098, *C.A.*, **34**, 7934 (1940).

169. Scudi, *Ind. Eng. Chem., Anal. Ed.*, **10**, 346 (1938).

170. Van Zyp, *Pharm. Weekblad*, **75**, 585 (1938).

171. Towne and Hitchens, *J. Am. Chem. Pharm. Assoc.*, **28**, 585 (1939).

172. Hoshall, *J. Assoc. Official Agri. Chem.*, **22**, 748 (1939); Schulek and Boldizár, *Z. anal. Chem.*, **108**, 396 (1937).

173. Marshall, *J. Biol. Chem.*, **122**, 263 (1937); Marshall and Litchfield, *Science*, **88**, 85 (1938).

174. Doble and Geiger, *J. Lab. Clin. Med.*, **23**, 651 (1938); Giordano and Prestrud, *Am. J. Clin. Path., Tech. Suppl.*, **4**, 88 (1940).

175. Bratton, Marshall, Babbitt, and Hendrickson, *J. Biol. Chem.*, **128**, 537 (1939).
176. Fantl, *Australian J. Exptl. Biol. Med. Sci.*, **18**, 175 (1940); *C.A.*, **34**, 6961 (1940).
177. Scudi, *J. Biol. Chem.*, **122**, 539 (1938).
178. Stevens and Hughes, *J. Am. Pharm. Assoc.*, **27**, 36 (1938); Fuller, *Lancet*, I, 194 (1937); Bauer and Gunderson, *Cornell Vet.*, **28**, 299 (1938); Maher and Camp, *J. Lab. Clin. Med.*, **24**, 1198 (1939); MacLachlan, Carey, and Butler, *ibid.*, **23**, 1273 (1938); Servantie and Demange, *J. pharm. chim.*, **30**, 162 (1939); Jauerneck and Gueffroy, *Klin. Wochschr.*, **16**, 1544 (1937); Proom, *Lancet*, I, 260 (1938).
179. Schmidt, *J. Biol. Chem.*, **122**, 757 (1938); *J. Lab. Clin. Med.*, **23**, 648 (1938); **24**, 982 (1939).
180. Scudi, Ratish, and Bullowa, *J. Am. Chem. Soc.*, **61**, 2554 (1939).
181. Werner, *Lancet*, I, 18 (1939); Williams, *Rocky Mt. Med. J.*, **37**, 110 (1940).
182. Yakowitz, *J. Assoc. Official Agri. Chem.*, **21**, 351 (1938).
183. Monti, *Gazz. chim. ital.*, 69, 749 (1939).
184. Wyss-Chodat and Paillard, *Compt. rend. soc. phys. hist. nat. Genève*, **56**, 50 (1939).
185. Wyss-Chodat and Paillard, *ibid.*, **56**, 61 (1939).
186. Barkan, *Science*, **92**, 107 (1940).
187. Macarovici, *Bul. Soc. Stiünte Cluj*, 9, 426 (1940); *C.A.*, **34**, 7532 (1940).
188. Scudi and Robinson, *J. Lab. Clin. Med.*, 25, 404 (1940); James, *Analyst*, **65**, 206 (1940).
189. Mossini, *Boll. soc. ital. biol. sper.*, **14**, 387 (1939).
190. Burkat, *Farm. Zhur.*, **12**, No. 2, 28 (1939); *C.A.*, **34**, 7535 (1940).
191. Roblin and Bell, *Science*, **90**, 327 (1939); see also Barkan, *Proc. Soc. Exptl. Biol. Med.*, **41**, 535 (1939).
192. Mingoia, *Ann. chim. farm.*, 48, April, 1939; *C.A.*, **33**, 5126 (1939).

SOME N-SUBSTITUTED DERIVATIVES OF SULFONAMIDES

1. Inglis, *J. Soc. Chem. Ind.*, **37**, 288T (1918); Miermeister, *Z. Untersuch. Lebensm.*, **59**, 585 (1930).
2. Dakin, Cohen, Daufresne, and Kenyon, *Proc. Roy. Soc. London*, **89B**, 232 (1916); Briscoe, *Chem. Age*, 9, 168 (1923).
3. Philipp, German pat., 504,997, *C.A.*, **25**, 522 (1931); see also Günzler, U. S. pat., 1,699,888, *C.A.*, **23**, 1138 (1929).
4. Roberts, *J. Chem. Soc.*, **123**, 2707 (1923).
5. Roberts, *ibid.*, **123**, 849 (1923).
6. Zil’berg, *Org. Chem. Ind.* (*U.S.S.R.*), **3**, 26 (1937); Dakin and Dunham, *Brit. Medical J.*, I, 683 (1917); Proschko, German pat., 492,249, *Chem. Zentr.*, I, **2630** (1930); U. S. pat., 1,697,139, *C.A.*, **23**, 1138 (1929); Claas, German pat., 318,899, *Chem. Zentr.*, IV, 14 (1920); see also Zil’berg, *Khim. Farm. Prom.*, No. **2**, 114 (1935).
7. Clutterbuck and Cohen, *J. Chem. Soc.*, **121**, 120 (1922).
8. Clutterbuck and Cohen, *ibid.*, **123**, 2507 (1923).
9*a*. Kastle, *Am. Chem. J.*, **17**, 704 (1895). *b*. Kastle, Keiser, and Bradley, *ibid.*, **18**, 491 (1896).

10. Chattaway, *J. Chem. Soc.*, **87**, 145 (1905).

11. Mirau, German pat., 530,894, *C.A.*, **26**, 153 (1932); U. S pat., 1,944,568, *C.A.*, **28**, 2013 (1934).

12. Dakin *et al.*, *J. Am. Med. Assoc.*, 69, 27 (1917).

13*a*. Krauss and Crede, *J. Am. Chem. Soc.*, **39**, 2720 (1917); Krauss, *J. Am. Pharm. Assoc.*, **7**, 46 (1918); *Am. J. Pharm.*, 90, 16 (1918). *b*. Chrzaszczewska and Dobrowolski, *Roczniki Chem.*, **17**, 411 (1937); *C.A.*, **32**, 1674 (1938); Stern and Taub, *J. Am. Pharm. Assoc.*, **28**, 1032 (1939).

14*a*. Baxter and Chattaway, *J. Chem. Soc.*, **107**, 1814 (1915). *b*. Gebauer-Fülnegg and Jusa, *Monatsh.*, **50**, 61 (1928).

15. Hoogerwerff and Van Dorp, *Rec. trav. chim.*, **6**, 373 (1887).

16. Schiemann and Novak, *Z. angew. Chem.*, **40**, 1032 (1927).

17*a*. Chaplin and Hunter, *J. Chem Soc.*, 1114 (1937). *b*. Bebie, *J. Am. Pharm. Assoc.*, **9**, 974 (1920).

18. Jungmichl and Hackl, *Melliand Textilber.*, **7**, 850 (1926); Komarovskii, Filonova, and Korenman, *J. Applied Chem.* (*U.S.S.R.*), 6, 742 (1933).

19*a*. Engfeldt, *Z. physiol. Chem.*, **126**, 1 (1923); Eisenschimmel, *C.A.*, **23**, 4408 (1929); Dietzel, Täufel, and Reder, *Apoth. Ztg.*, **44**, 989, 1007 (1929). *b*. Milbauer, *Congr. int. phot. sci. appl.*, 9, 294 (1936); *C.A.*, **34**, 3988 (1940).

20. Leech, *J. Am. Pharm. Assoc.*, **12**, 592 (1923).

21. Dunham and Dakin, *Brit. Med. J.*, II, 790 (1917).

22. Salkin, *J. Am. Pharm. Assoc.*, **13**, 613 (1924); Harris, *Science*, **51**, 20 (1920).

23*a*. Young, U. S. pat., 1,451,857, *C.A.*, **17**, 2033 (1923); Chemische Fabrik von Heyden A.-G., French pat., 784,238, *C.A.*, **30**, 106 (1936). *b*. Steingroever and Boser, German pat, 639,788, *C.A.*, **31**, 4066 (1937).

24*a*. Hoogewerff and Van Dorp, *Rec. trav. chim.*, 6, 373 (1887). *b*. Kastle, *Am. Chem. J.*, **45**, 219 (1911). *c*. Coleman, *Proc. Iowa Acad. Sci.*, **46**, 217 (1939).

25. Soper, *J. Chem. Soc.*, **125**, 1899 (1924); Pryde and Soper, *ibid.*, 1514 (1931).

26. Philipp, German pat., 514,094, *C.A.*, **25**, 1262 (1931); German pat., 515,465, *C.A.*, **25**, 1841 (1931).

27*a*. Curl and Fernelius, *J. Am. Chem. Soc.*, **53**, 1478 (1931). *b*. Orton and Bradfield, *J. Chem. Soc.*, 986 (1927).

28*a*. Markees, *Pharm. Acta Helv.*, **6**, 106 (1931). *b*. Gorton, *Svensk. Farm. Tids*, **33**, 281 (1929). *c*. Lestra, *Bull. sci. pharmacol.*, **46**, 26 (1939).

29*a*. Tomíček and Sucharda, *C.A.*, **26**, 1210 (1932). *b*. McMillan and Easton, *J. Soc. Chem. Ind.*, **46**, 472T (1927). *c*. Singh and Rehmann, *J. Indian Chem. Soc.*, **17**, 169 (1940).

30. Komarovskii, Filonova, and Korenmann, *J. Applied Chem.* (*U.S.S.R.*), **6**, 742 (1933); *Z. anal. Chem.*, **96**, 321 (1934).

31. Van Eck, *Pharm. Weekblad*, **63**, 1117 (1926).

32. Noll, *Chem.-Ztg.*, **48**, 845 (1924); anon., *Chimie & industrie*, **15**, 783 (1926).

33*a*. Jungmichl and Hackl, *Melliand Textilber.*, **7**, 850 (1926). *b*. Noll, *Papier-Fabr.*, **38**, 86 (1940).

34. Coull, Hope, and Gouguell, *J. Am. Chem. Soc.*, **57**, 1489 (1935).

35. Makower and Bray, *ibid.*, **55**, 4765 (1933); Makower, *ibid.*, **56**, 1315 (1934).

36. Herzog, *Oesterr. Chem.-Ztg.*, **29**, 26 (1926).

37. Bradfield, Orton, and Roberts, *J. Chem. Soc.*, **782** (1928).

38. Berthelot and Michel, *Bull. sci. pharmacol.*, **26**, **401** (1919).

39. Herzog, *Chem. Umschau Fette, Öle, Wachse, Harze,* **37**, 296 (1930); Margosches and Frischer, *Chem.-Ztg.*, **61**, 519 (1927).
40. Dakin, *Biochem. J.*, **11**, 79 (1917).
41. Koetschet and Koetschet, *Helv. Chim. Acta,* **12**, 669 (1929).
42. Koetschet, Koetschet, and Viaud, *ibid.*, **13**, 587 (1930).
43. Nicolet and Willard, *Science,* **53**, 217 (1921).
44. Mann and Pope, *J. Chem. Soc.*, **121**, 1052 (1922); Petrov, *J. Gen. Chem. (U.S.S.R.)*, 9, 1635 (1939); *C.A.*, **34**, 3703 (1940).
45. Alexander and McCombie, *J. Chem. Soc.*, 2087 (1932).
46. Chaplin and Mann, *Nature,* **135**, 686 (1934); Mann and Chaplin, *J. Chem. Soc.*, 527 (1937).
47. Mann, *ibid.*, 958 (1932).
48. Burton and Gibson, *ibid.*, **125**, 2275 (1924).
49. Le Fèvre, *J. Chem. Soc.*, 1745 (1932).
50. I. G. Farbenindustrie A.-G., British pat., 445,739, *C.A.*, **30**, 6895 (1936).
51*a*. Földi, *Ber.*, **63B**, 2257 (1930). *b*. Kharasch and Priestley, *J. Am. Chem. Soc.*, **61**, 3425 (1939). *c*. Milne, Ph.D. thesis, Northwestern University, 1941.
52. Likhosherstov and Arkhangel'skaya, *J. Gen. Chem. (U.S.S.R.)*, **7**, 1914 (1937).
53. Likhosherstov and Shalaeva, *J. Gen. Chem. (U.S.S.R.)*, **8**, 370 (1938); *C.A.*, **32**, 5369 (1938).
54*a*. Likhosherstov, Zhabotinskaya, Pavlovskaya, and Ponomarenko, *J. Gen. Chem. (U.S.S.R.)*, **8**, 997 (1938); *C.A.*, **33**, 3761 (1939). *b*. Petrov, *J. Gen. Chem. (U.S.S.R.)*, **8**, 208 (1938); *C.A.*, **32**, 5370 (1938).
55. Likhosherstov and Petrov, *J. Gen. Chem. (U.S.S.R.)*, 9, 2000 (1939); 9, 2012 (1939).
56*a*. Dakin, Cohen, and Kenyon, *Brit. Med. J.*, I, 160 (1916). *b*. Vincent, *J. Exp. Med.*, **26**, 83 (1917). *c*. Daufresne, *ibid.*, **26**, 91 (1917); Carrel and Hartmann, *ibid.*, **26**, 95 (1917).
57. Austin and Taylor, *ibid.*, **27**, 627 (1918); Cullen and Taylor, *ibid.*, **28**, 681 (1918); Eicher, *J. Am. Pharm. Assoc.*, 6, 387 (1917); Bougault, *J. pharm. chim.*, **16**, 274 (1917); Langstein, *Wiener. Med. Wochschr.*, **76**, 1533 (1926).
58*a*. Wallis, *Indian J. Med. Research,* **4**, 800 (1917); Adams, *Water Eng.*, **29**, 361 (1927). *b*. Adams, *Brit. Med. J.*, II, 184 (1917); Dakin and Dunham, *ibid.*, I, 683 (1917). *c*. Fantus, *J. Am. Pharm. Assoc.*, **7**, 1034 (1918); *J. Infect. Dis.*, **24**, 191 (1919).
59. Tilley, *J. Agri. Research,* **20**, 85 (1920); Koser, *Centr. Bakt. Parasitenk. I Abt,* 99, 164 (1926); Dietzel and Schlemmer, *Arch. Pharm.*, **266**, 173 (1928); Kinugasa and Nishihara, *J. Pharm. Soc. Japan,* No. **454**, 1006 (1919).
60. Dietrich and Fleischhauer, *Centr. Bakt. Parasitenk.*, I, **104**, 429 (1927).
61. Bergin, *ibid.*, Orig. **92**, 465 (1924); see also Tilley, ref. 59.
62. Johns, *Sci. Agri.*, **16**, 218 (1934); Charlton and Levine, *J. Bact.*, **30**, 163 (1935); *Iowa Eng. Expt. Sta. Bull.*, **132**, 60 pp. (1937); Charlton, *Iowa State Coll. J. Sci.*, **13**, 54 (1938).
63. Thomann, *Schweiz. Apoth.-Ztg.*, **65**, 73, 85 (1927); Saiko-Pittner, *Pharm. Presse,* **31**, 411 (1926); Smyth, *Am. J. Pharm.*, **95**, **232** (1923); Harris, *Science,* **61**, **20** (1920); Cook, *Am. J. Pharm.*, **90**, 629 (1918); Johns, *Sci.*

Agri., **10**, 553 (1930); Fetscher, *Z. Desinfekt. u. Gesundh.*, **20**, 78 (1928); Hermann, *Pharm. Zentralhalle*, **69**, 273 (1928); Leusden, *Arch. Hyg.*, **105**, 229 (1931); Laubenheimer, *ibid.*, **107**, 386 (1932); Lüers and Weinfurtner, *Wochschr. Brau.*, **43**, 25, 35, 45 (1926); anon., *Pharm. Ztg.*, **68**, 87 (1923); Supfle, *Arch. Hyg.*, **97**, 176 (1926); Guiteras and Schmelkes, *J. Biol. Chem.*, **107**, 235 (1934).

64. Aufrecht, *Pharm. Ztg.*, **68**, 765 (1923); Bergin, *Z. Tuberk*, **49**, 355 (1928); Hailer, *Arb. Reichsgesundh.*, **57**, 703 (1926); Carrieu and Boulouys, *Rev. hyg.*, **47**, 514 (1925); Brunk, *Centr. Bakt. Parasitenk.*, I, Orig. **94**, 236 (1925); Bergin, *ibid.*, **92**, 465 (1924); Horel, *Dental Cosmos*, **61**, 373 (1919); Tarbouriech, *Bull. sci. pharmacol.*, **27**, 269 (1920); Wesenberg, *Z. angew. Chem.*, **39**, 1004 (1926); Johns, *Can. Pub. Health J.*, **21**, 162 (1930); Eicher, *J. Am. Pharm. Assoc.*, **6**, 387 (1917); Thompson, Isaacs, and Khorazo, *Am. J. Ophthalmol.*, **20**, 1087 (1937).

65. Grünwald and Bass, *Klin. Wochschr.*, **1**, 2278 (1922); Fantus and Smith, *J. Pharmacol.*, **14**, 259 (1919); Wegeforth and Errick, *ibid.*, **13**, 335 (1919); Jürgens, *Z. ges. exptl. Med.*, **25**, 123 (1921).

66. Wollstein and Meltzer, *Proc. Soc. Exp. Biol. Med.*, **15**, 58 (1918); *J. Exp. Med.*, **27**, 725 (1918).

67. Dakin *et al.*, *J. Am. Med. Assoc.*, **69**, 27 (1917); Dakin and Dunham, *Brit. Med. J.*, I, 51 (1918); see Steingroever and Boser, German pat., 639,788, *C.A.*, **31**, 4066 (1937) for use of chlorinated diphenyl ether as a solvent.

68. Lee and Furness, *Ann. Surg.; Midland Druggist*, **53**, 82 (1919); Sweet, *Brit. Med. J.*, II, 249 (1917).

69. McClelland and Waas, *Dental Cosmos*, **64**, 56 (1922); Fantus and Smith, *J. Pharmacol.*, **14**, 259 (1919); Dunham, *Brit. Med. J.*, I, 865 (1917); Cullen and Taylor, *J. Exp. Med.*, **28**, 681 (1918); Soto, *J. Am. Med. Assoc.*, **71**, 1015 (1918); Sollmann, *ibid.*, **72**, 992 (1919); Dunham, *ibid.*, **70**, 571 (1918); Tarbouriech, *Bull. soc. pharmacol.*, **27**, 269 (1920).

70. Hebbeler, *Chem.-Ztg.*, **50**, 578 (1926).

71. Loveless, *Vt. Agr. Expt. Sta., Bull.*, 369, 3 (1934).

72. Miermeister, *Z. Untersuch. Lebensm.*, **59**, 289 (1930); Ewe, *Am. J. Pharm.*, **105**, 296 (1933).

73. Feibelmann, *Chem.-Ztg.*, **48**, 685 (1924); Heermann, *Textilber.*, **5**, 181 (1924); De Puyster, *Color Trade J.*, **16**, 137 (1925); Wagener, *Textilber.*, **7**, 446 (1926); *C.A.*, **20**, 2251 (1926); Trotman, *Dyer, Calico Printer*, **63**, 144 (1930); Haller and Seidel, *Am. Dyestuff Reptr.*, **18**, 85 (1929).

74. Feibelmann, *Textilber.*, **7**, 47 (1926); Hausner, *ibid.*, **8**, 244 (1927).

75. Haller and Seidel, *Z. angew. Chem.*, **41**, 698 (1928).

76. Hausner, *Pharm. Zentralhalle*, **67**, 115 (1926).

77. Feibelmann, *Textilber.*, **7**, 144 (1926); Haller and Hohmann, *ibid.*, **7**, 239 (1926); Hausner, *Rayon*, **12**, No. 6, 36 (1931); Walton, *Am. Dyestuff Reptr.*, **16**, 789 (1927); Mehta, *Indian Textile J.*, **45**, 137 (1935); Feibelmann, *ibid.*, **41**, 317 (1931); for general discussions of its uses in textile industry see Feibelmann, *Chem.-Ztg.*, **48**, 297 (1924); Tatu, *Tiba*, **11**, 883 (1933); Münch, *Z. ges. Textil-Ind.*, **32**, 372 (1929); Hall, *Dyer, Calico Printer*, **56**, 150 (1926); Quick, *Can. Colorist Textile Processor*, **7**, 12, 20, 50, 59, 66 (1927); Lagache, *Tiba*, **5**, 145 (1927); Wagener, *Textilber.*, **7**, 446 (1926); *C.A.*, **21**, 2802 (1927); Waeser, *Chem.-Ztg.*, **49**, 853 (1925);

Anon., *Dyer, Calico Printer,* **58**, 68, 85 (1927); Meinecke, *Metallborse,* **16**, 873 (1926); Bach, *ibid.*, **17**, 985 (1927).

78. Feibelmann, *Textilber.*, **8**, **714** (1927); Hausner, *Rayon,* **12**, No. 6, 36 (1931); Hall, *Dyer, Calico Printer,* **56**, 150 (1926).
79. Dalström, *Svensk Kem. Tids,* **88**, 96 (1926).
80. Popov, *Khim. Farm. Prom.*, **7**, 282 (1932).
81. Graham, *J. Assoc. Official Agri. Chem.*, **18**, 156 (1935).
82. Krais and Meves, *Chem.-Ztg.*, 49, 656 (1925).
83. Van der Meulen, *Chem. Weekblad,* **31**, 558 (1934).
84. Van Urk, *ibid.*, **26**, 9 (1929).
85. Rupp, *U. S. Dept. Agri. Bull.*, **1114**, 1 (1922).
86. Weinstein, Muesmann, and Bodschwinna, *Z. Untersuch. Lebensm.*, **61**, **436** (1931).

87*a*. Piloty, *Ber.*, **29**, 1560 (1896). *b*. Meyer, *J. prakt. Chem.*, [2] **63**, 175 (1901). *c*. Angeli, Angelico, and Scurti, *Atti accad. Lincei,* [5] **11**, I, 557 (1902). *d*. Kharasch and Reinmuth, U. S. pat., 2,097,415, *C.A.*, **32**, 1407 (1938); British pat., 506,431, *C.A.*, **33**, 9553 (1939).

88*a*. Moore, Miller, and Miller, *J. Am. Chem. Soc.*, **62**, 2097 (1940). *b*. Main, Shinn, and Mellon, *Proc. Soc. Exptl. Biol. Med.*, **43**, 593 (1940); **44**, 596 (1940).

89. Angeli and Marchetti, *Atti accad. Lincei,* [5] **17**, I, 696 (1908).
90. Rimini, *ibid.*, [5] **10**, I, 355 (1901); Oddo and Deleo, *Ber.*, **69B**, 294 (1936); Cambi, *Ber.*, **69B**, 2027 (1936).
91. Angeli, *Atti accad. Lincei,* [5] **20**, II, 447 (1911); **21**, I, 622 (1912); **22**, I, 851 (1913); Balbiano, *ibid.*, [5] **20**, II, 248 (1911); **21**, I, 390 (1912); **22**, I, 576 (1913).
92. Hantzsch and Sauer, *Ann.*, **299**, 81 (1898).

93*a*. Königs, *Ber.*, **11**, 616 (1878). *b*. Fichter and Tamm, *Ber.*, **43**, 3034 (1910). *c*. Angeli, Angelico, and Scurti, *Gazz. chim. ital.*, **33**, II, 309 (1903).

94. Hinsberg, *Ber.*, **27**, 598 (1894).
95. Königs, *Ber.*, **11**, 1589 (1878); Otto and Ostrop, *Ann.*, **141**, 370 (1867); Otto and v. Gruber, *Ann.*, **146**, 19 (1868).
96. Curtius and Lorenzen, *J. prakt. Chem.*, [2] **58**, 166 (1898).
97. McFadyen and Stevens, *J. Chem. Soc.*, 584 (1936).
98. Price, May, and Pickel, *J. Am. Chem. Soc.*, **62**, 2818 (1940).
99. Buchman and Richardson, *ibid.*, **61**, 891 (1939).
100. Harington and Rivers, *J. Chem. Soc.*, 1101 (1940).
101. Bayer and Co., German pat., 224,388, *Frdl.*, **10**, 1216.
102. Ihrfelt, *Ber.*, **22R**, **692** (1889); Wallin, *Acta Universitaties Lundensis,* **28**, part 2, III, 13 (1892).
103. Hinsbebg, *Ber.*, **25**, 1093 (1892).
104. Van Romburgh, *Rec. trav. chim.*, **3**, 16 (1884).
105. Hinsberg, *Ber.*, **27**, 600 (1894).

SACCHARIN AND RELATED COMPOUNDS

1. Remsen and Fahlberg, *Ber.*, **12**, 469 (1879); *Am. Chem. J.*, **1**, 426 (1880). Fahlberg noted that the bread he ate after working in the laboratory one day had a sweet taste. This proved to be due to traces of saccharin remaining on his hands.

2. McKie, *J. Soc. Chem. Ind.*, **40**, 92 (1921); *J. Chem. Soc.*, **113**, 799 (1918).

3. Terlinck, *Ingénieur chimiste*, **8**, 233 (1924); **9**, 13 (1925).

4. Remsen, *Am. J. Sci.*, **5**, 179, 274, 354 (1873); *Ann.*, **178**, 275 (1875).

5. Fahlberg, German pat., 35,211, *Frdl.*, **1**, 590; Fahlberg and List, *Ber.*, **21**, 243 (1888).

6. Pamfilov, *C.A.*, **17**, 1445 (1923).

7*a*. Orelup, U. S. pat., 1,601,505, *C.A.*, **20**, 3696 (1926). *b*. Zaikov and Sokolov, *J. Chem. Ind. (Moscow)*, **3**, 1304 (1926). *c*. Zil'berg, *Khim. Farm. Prom.*, No. 4, 22 (1934). *d*. Bebie, U. S. pat., 1,366,349, *C.A.*, **15**, 1030 (1921).

8. Soc. chim. des usines du Rhone, British pat., 153,520, *C.A.*, **15**, 1030 (1921); British pat., 165,438, *C.A.*, **16**, 424 (1922); Altwegg and Collardeau, U. S. pat., 1,507,565, *C.A.*, **18**, 3386 (1924).

9. Magidson and Zil'berg, *J. Gen. Chem. (U.S.S.R.)*, 5, 920 (1935).

10. Chem. Fabr. von Heyden, German pat., 85,491, *Frdl.*, **4**, 1263; Lowe, British pat., 174,913, *C.A.*, **16**, 1710 (1922); N. V. Industri ele Maataschappij Voorheen Nowry and van der Lande, Dutch pat., 41,338, *C.A.*, **31**, 8399 (1937); Halla, *Z. Elektrochem.*, **36**, 96 (1930).

11. Fichter and Löwe, *Helv. Chim. Acta*, **5**, 60 (1922).

12. Klages, Swiss pat., 78,277, *C.A.*, **13**, 2374 (1919).

13. Belani, *Chem.-Ztg.*, **49**, 877 (1925); Dyson, *Chem. Age (London)*, **11**, 572 (1924); Lorges, *Rev. chim. ind.*, **35**, 109 (1926); Barral and Ranc, *l'ind. chim.*, 6, 73 (1919); Murayama, Aoyama, and Tomida, *J. Pharm. Soc. Japan*, No. 438, 632 (1918); Hansen, *Dansk. Tids. Farm.*, **1**, 114 (1926); Durocher, *La Nature*, **53**, ii, 361 (1925); anon., *Ind. Chemist*, **1**, 5 (1925); Beyer, "Handbuch der Saccharin Fabrikation," Zurich, Rascher and Co., 1923, 143 pp.

14*a*. Noyes, *Am. Chem. J.*, **8**, 179 (1886). *b*. Chem. Fabr. vorm Sandoz, German pat., 113,720, *Chem. Zentr.*, II, 794 (1900); *Frdl.*, **6**, 1209.

15. Bradshaw, *Am. Chem. J.*, **35**, 337 (1906).

16. Wilson, *ibid.*, **30**, 363 (1903).

17. Fahlberg and List, *Ber.*, **20**, 1596 (1887); Fahlberg, German pat., 103,298, *Chem. Zentr.*, II, 928 (1899); Bayer and Co., German pat., 96,125, *ibid.*, 1, 1224 (1898).

18. Kreis, *Ann.*, **286**, 388 (1895).

19. Basler, Chem. Fabr., German pat., 80,713, *Frdl.*, **4**, 1266.

20. Remsen and Saunders, *Am. Chem. J.*, **17**, 351 (1895); Remsen and McKee, *ibid.*, **18**, 805 (1896); List and Stein, *Ber.*, **31**, 1656 (1898); Remsen and Bird, *Am. Chem. J.*, **30**, 266 (1903); Fahlberg, German pat., 35,717, *Frdl.*, **1**, 593.

21. Remsen and Humphreys, *Am. Chem. J.*, **30**, 305 (1903).

22*a*. Basler, Chem. Fabr., German pat., 122,567, *Chem. Zentr.*, II, 447 (1901); *Frdl.*, 6, 1208. *b*. Koetschet and Koetschet, *Helv. Chim. Acta*, **12**, 669 (1929). *c*. Hart, McClelland, and Fowkes, *J. Chem. Soc.*, 2114 (1938); Bartlett, Hart, and McClelland, *ibid.*, 760 (1939).

23. Gillard, Monnet, and Cartier, German pat., 94,948, *Chem. Zentr.*, I, 540 (1898); *Frdl.*, **5**, 874.

24*a*. Walker and Smith, *J. Chem. Soc.*, **89**, 352 (1906). *b*. Jesurun, *Ber.*, **26**, 2287 (1893). *c*. Fritsch, *Ber.*, **29**, 2295 (1896). *d*. Maselli, *Gazz. chim. ital.*, **30**, II, 534 (1900).

25*a*. Herzog, *Z. angew. Chem.*, **39**, 728 (1926). *b*. Klages, Sturm, and Weniger, *J. prakt. Chem.*, **116**, 163 (1927).

26. Herzog, "Die Verwertung der Nebenprodukte der Saccharinfabrikation," F. Enke, Stuttgart, 1929, 170 pp.; Herzog, *Kunstoffe*, **16**, 105 (1926); *Oesterr. Chem.-Ztg.*, **29**, 26 (1926); *Pharm. Zentralhalle*, **67**, 81 (1926); *Metallborse*, **18**, 903, 1015, 1126, 1183, 2191 (1928); **19**, 1853 (1929); *Z. ges. Textil-Ind.*, **32**, 857, 873, 889 (1929); *Z. wiss. Phot.*, **27**, 177 (1929); *Chem.-Ztg.*, **54**, 50 (1930); *C.A.*, **25**, 428, 2810 (1931).

27. Täufel, Wagner, and Preiss, *Z. Elektrochem.*, **34**, 281 (1928); see also Kolthoff, *Rec. trav. chim.*, **44**, 629 (1925); Imbesi and De Angelis, *Ann. chim. applicata*, **25**, 254 (1935).

28. Pritzker, *Schweiz. Apoth.-Ztg.*, **58**, 29, 78 (1920); Beyer, *Chem.-Ztg.*, 43, 751 (1919).

29*a*. Evans and Dehn, *J. Am. Chem. Soc.*, **52**, 1028 (1930). *b*. Lyons, *ibid.*, **47**, 830 (1925).

30. Bebie, *J. Am. Pharm. Assoc.*, **19**, 371 (1930).

31. Bhatnager, Mathur, and Budhiraja, *Z. physik. Chem.*, **A163**, 8 (1932).

32. Grossfeld, *Z. Ges. Kohlensaure Ind.*, No. 15, 253 (1921).

33. Paul, *Z. Nahr. u. Genussm.*, **43**, 137 (1922); *Z. Elektrochem.*, **27**, 539 (1921); Magidson and Gorbachov, *Ber.*, **56B**, 1810 (1923); Beyer, *Schweiz. Chem.-Ztg.*, 598 (1920); Pauli, *Biochem. Z.*, **125**, 97 (1921).

34. Helch, *Pharm. Post; Schweiz. Apoth.-Ztg.*, **55**, 239 (1917).

35. Paul, *Chem.-Ztg.*, **45**, 705 (1921).

36*a*. Täufel and Wagner, *Ber.*, **58B**, 909 (1925). *b*. Cragg, *Trans. Roy. Soc. Can.*, **31**, III, 131 (1937).

37. Täufel and Klemm, *Z. Nahr. u. Genussm.*, **50**, 264 (1925).

38*a*. Paul, *Chem.-Ztg.*, **45**, 38 (1921). *b*. Bruhns, *Centr. Zuckerind.*, **29**, 725 (1921). *c*. Oddo and Perotti, *Gazz. chim. ital.*, **67**, 543 (1937).

39. Neumann, *Z. Nahr. u. Genussm.*, **47**, 184 (1924); Serger and Clarck, *Konserven Ind.*, **18**, 244 (1931); see also Hynes, *Dairy Inds.*, **4**, 348 (1939).

40*a*. Traegel, *Z. Ver. deut. Zuckerind.*, **75**, 345 (1925); *Deut. Zuckerind.*, **50**, 1175 (1925). *b*. Annecke, *Deut. Apoth.-Ztg.*, **54**, 244 (1939).

41. Anon., *Chem.-Ztg.*, **46**, 361 (1922).

42. Raimon, *Ind. chim.; Giorn. farm. chim.*, **66**, 5 (1917).

43. Jagoda, *Z. Ver. deut. Zucker-Ind.*, 243 (1927).

44. Heimann, *C.A.*, **17**, 3548 (1923).

45. Blodgett, *Med. Rec.*, **97**, 521 (1920); Neumann, *Arch. Hyg.*, **96**, 264 (1925); Althausen and Wever, *Proc. Soc. Exptl. Biol. Med.*, **35**, 517 (1937); Fischler and Schroeter, *Deut. Med. Wochschr.*, **61**, 1354 (1935).

46*a*. Lehmann, *Arch. Hyg.*, **101**, 39 (1929). *b*. Miyadera, *Z. physik. diätet. Therap.*, **26**, 232 (1922). *c*. De Nito, *Boll. soc. ital. biol. sper.*, **11**, 934 (1936). *d*. Diemair and Fischler, *Biochem. Z.*, **239**, 232 (1931). *e*. Fantus and Hektoen, *J. Am. Pharm. Assoc.*, **12**, 318 (1923).

47. Schwarz and Büchlmann, *Fermentforschung*, **7**, 282 (1924); Schwarz and Zelinger, *ibid.*, **7**, 300 (1924).

48. Best, *Physiol. Abstracts*, **2**, 623 (1918); Haramaki, *Z. physik. diätet. Therap.*, **26**, 183 (1922); Demianowski and Hefter, *Physiol. Abstracts*, **7**, 607 (1923); see, however, Bleyer, Diemair, and Leonhard, *Arch. Pharm.*, **271**, 539 (1933); Dobreff, *Arch. Hyg.*, **95**, 320 (1925).

49. Bleyer and Fischer, *Biochem. Z.*, **238**, 212 (1931).

50. Ciaccio and Racchiusa, *Boll. soc. ital. biol. sper.*, **2**, 309 (1927); for effect upon catalases of blood see Becht, *J. Pharmacol.*, **16**, 155 (1920); Burge, *Science*, **48**, 549 (1918).

51. Carlson, Eldridge, Martin, and Foran, *J. Metabolic Research*, **3**, 451 (1923).

52. Heitler, *Physiol. Abstracts*, **5**, 573 (1921); Wiener, *Klin. Wochschr.*, **35**, 935 (1922).

53. Uglow, *Arch. Hyg.*, 92, 331 (1924).

54*a*. Harvey, *Am. J. Pharm.*, 90, 105 (1923); for toxicity to plants see Verschaffelt, *Pharm. Weekblad*, **52**, 37 (1915). *b*. C. N. Andersen, U. S. pat., 2,087,959, *C.A.*, **31**, 6827 (1937); U. S. pat., 2,135,553, *C.A.*, **33**, 1448 (1939); U. S. pat., 2,155,922, *C.A.*, **33**, 6001 (1939); H. P. Anderson and Hart, *J. Am. Chem. Soc.*, **59**, 1115 (1937).

55. Richmond and Hill, *J. Soc. Chem. Ind.*, **38**, 8T (1919).

56. Täufel and Naton, *Z. angew. Chem.*, **39**, 224 (1926); Dietzel and Täufel, *Z. Nahr. u. Genussm.*, **49**, 65 (1925).

57*a*. Fahlberg and List, *Ber.*, **21**, 245 (1888). *b*. Täufel, Wagner, and Preiss, *Z. Elektrochem.*, **34**, 281 (1928).

58. Fahlberg and Barge, *Ber.*, 22, 755 (1889); Remsen and Linn, *Am. Chem. J.*, **11**, 73 (1889); Remsen and Burton, *ibid.*, **11**, 404 (1889); Krannich, *Ber.*, **33**, 3485 (1900); Clark and Dreger, *Org. Syntheses*, 9, 1 (1929).

59. Krantz, *J. Assoc. Official Agr. Chem.*, **16**, 316 (1933); **17**, 193 (1934); Lerrigo and Williams, *Analyst*, **52**, 377 (1927); Heesterman, *Chem. Weekblad*, 29, 130 (1932); Beyer, *Chem.-Ztg.*, **44**, 437 (1920); Richmond and Hill, *J. Soc. Chem. Ind.*, **37**, 246 (1918); **38**, 8T (1919); Olszewski, *Pharm. Zentralhalle*, 61, 583 (1920); Hefelmann, *Pharm. Post.*, 675 (1917); *Schweiz. Apoth.-Ztg.*, **56**, 145 (1918); McKie, *J. Soc. Chem. Ind.*, **40**, 150T (1921); Proctor, *J. Chem. Soc.*, **87**, 242 (1905); for other analytical methods see p. 630.

60*a*. Gianformaggio, *Gazz. chim. ital.*, **50**, I, 327 (1920). *b*. Matsui, Sawamura, and Adachi, *Mem. Coll. Sci. Kyoto Imp. Univ.*, **A15**, 151 (1932).

61. Remsen and Palmer, *Am. Chem. J.*, 8, 227 (1886); Brackett, *ibid.*, 9, 406 (1887); Fahlberg and List, *Ber.*, 20, 1596 (1887); Merritt, Levey, and Cutter, *J. Am. Chem. Soc.*, **61**, 15 (1939).

62. Braun, Heider, and Müller, *Ber.*, **51**, 273 (1918).

63*a*. Eckenroth and Koerppen, *Ber.*, **30**, 1267 (1897). *b*. Eckenroth and Klein, *Ber.*, **29**, 330 (1896).

64. Eckenroth and Koerppen, *Ber.*, **30**, 1265 (1897).

65. Braun and Lemke, *Ber.*, **55B**, 3526 (1922).

66. Lyons and Reid, *J. Am. Chem. Soc.*, **39**, 1727 (1917).

67. Heller, Buchwaldt, Fuchs, Kleinicke, and Kloss, *J. prakt. Chem.*, **111**, 1 (1925).

68. Remsen and Clark, *Am. Chem. J.*, **30**, 278 (1903).

69. Koetschet, Koetschet, and Viaud, *Helv. Chim. Acta*, **13**, 587 (1930).

70. McClelland, Warren, and Jackson, *J. Chem. Soc.*, 1582 (1929).

71. McClelland and Gait, *ibid.*, 921 (1926).

72. Remsen and Coates, *Am. Chem. J.*, **17**, 320 (1895); Remsen and Kohler, *ibid.*, **17**, 336 (1895); Remsen and Holmes, *ibid.*, **30**, 275 (1903); Remsen and Hunter, *ibid.*, **18**, 815 (1896); List and Stein, *Ber.*, **31**, 1658 (1898).

73*a*. Eckenroth and Koerppen, *Ber.*, 29, 1050 (1896). *b*. Ford, *Iowa State Coll. J. Sci.*, **12**, 121 (1937). *c*. Josephson, *Ber.*, **60B**, 1822 (1927). *d*. Finzi and Colonna, *Atti accad. Lincei, Classe sci. fis., mat. nat.*, **26**, 19 (1937); *C.A.*, **32**, 3762 (1938); *Gazz. chim. ital.*, **68**, 132 (1938); *C.A.*, **32**, 6638 (1938).

74. Hoogerwerff and Van Dorp, *Rec. trav. chim.*, **18**, 358–62 (1899).

75. Remsen and Dohme, *Am. Chem. J.*, **11**, 345 (1889).

76. Bertolo and Bertolo, *Gazz. chim. ital.*, **62**, 487 (1932).

77. Bertolo, *ibid.*, **41**, I, 698 (1911); *C.A.*, **6**, 3804 (1911).

78. Chattaway, *J. Chem. Soc.*, **87**, 1884 (1905).

79. Feigl and Chargaff, *Monatsh.*, **49**, 417 (1928).

80. Feigl and Bondi, *ibid.*, **53** and **54**, 508 (1929).

81. Mannessier-Mameli, *Gazz. chim. ital.*, **65**, 51 (1935).

82. Oddo and Mingoia, *ibid.*, **61**, 435 (1931).

83. Mannessier-Mameli, *ibid.*, **62**, 1067 (1932).

84*a*. Mannessier-Mameli, *ibid.*, **65**, 77 (1935); Bradshaw, *Am. Chem. J.*, **35**, 335 (1906).

85. Oddo and Mingoia, *Gazz. chim. ital.*, **57**, 465 (1927).

86. Sachs, Wolff, and Ludwig, *Ber.*, **37**, 3252, 3267 (1904); Sachs and Ludwig, *Ber.*, **37**, 390 (1904); Cobb and Fuller, *Am. Chem. J.*, **45**, 608 (1911).

87. Maselli, *Gazz. chim. ital.*, **30**, 33 (1900).

88. Fabre, *Bull. soc. chim.*, **33**, 791 (1923).

89. Dutt, *J. Chem. Soc.*, **121**, 2389 (1922).

90. Monnet and Koetschet, *Bull. soc. chim.*, [3] **17**, 694 (1897); Gilliard, Monnet, and Cartier, German pat., 100,779, *Chem. Zentr.*, I, 719 (1899).

91. Orndorff and Vose, *J. Am. Chem. Soc.*, **46**, 1897 (1924); Sisley, *Bull. soc. chim.*, [3] **17**, 822 (1897).

92. Earlier references are Herzfeld and Reischauer, *Z. anal. Chem.*, **27**, 396 (1888); Börnstein, *ibid.*, **27**, 165 (1888); *Ber.*, **21**, 3396 (1888); Hooker, *ibid.*, **21**, 3395 (1888); Remsen and Burton, *Am. Chem. J.*, **11**, 404 (1889); Gantter, *Z. anal. Chem.*, 32, 309 (1893); Hefelmann, *Pharm. Zentralhalle*, **35**, 105 (1894); **36**, 219 (1895); **37**, 279 (1896); *Chem. Zentr.*, II, 192 (1896); Eckenroth and Klein, *Ber.*, **29**, 329 (1896); Eckenroth and Koerppen, *Ber.*, **29**, 1048 (1896); Wauters, *Chem. Zentr.*, I. 576 (1896); Eckenroth, *ibid.*, I, 765 (1896); Langbein, *Z. angew. Chem.*, 9, 486 (1896).

93*a*. Merl and Lüft, *J. Chem. Soc.*, **112**, II, 383 (1911). *b*. Gnadinger, *J. Assoc. Official Agri. Chem.*, **3**, 25 (1917). *c*. Seeker, *ibid.*, **3**, 504 (1920). *d*. Wolf, *ibid.*, 6, 14 (1922). *e*. Reif, *Z. Nahr. u. Genussm.*, **46**, 217 (1923). *f*. Grossfeld, *Z. ges. Kohlensaure Ind.*, **26**, 143, 159 (1920).

94. Deniges, *Bull. soc. pharm. Bordeaux*, No. 2 (1921); *C.A.*, **16**, 312 (1922); Fischer, *Z. untersuch. Lebensm.*, **67**, 161 (1934); Staněk and Pavlas, *Z. Zuckerind. Čechoslovak Rep.*, **59**, 361 (1935); Mayrhofer, Herzig, and Zauder, *Pharm. Monatsh.*, **7**, 81, 109, 130 (1926); Votava, *Z. Zuckerind. Čechoslovak. Rep.*, **62**, 121 (1937).

95. Wagenaar, *Mikrochemie*, **5**, 132 (1932); *Pharm. Weekblad*, **69**, 614 (1932); Rosenthaler, *Mikrochemie*, **12**, 98 (1932); **21**, 215 (1937); Van Zijp, *Pharm. Weekblad*, **71**, 1146, 1151 (1934); Zwikker, *ibid.*, **70**, 551 (1933); Klasens and Terpstra, *Rec. trav. chim.*, **56**, 673 (1937).

96. Bonis, *Ann. fals.*, **11**, 369 (1919); Carlinfanti and Marzocchi, *C.A.*, **6**, 1378 (1912); Jamieson, *J. Biol. Chem.*, **41**, **3** (1920); Reindollar, *J. Assoc. Official Agr. Chem.*, **21**, 184 (1938).

97. Staněk and Pavlas, *Z. Zuckerind. Čechoslovak Rep.*, **58**, 313 (1934); *Mikrochemie*, **16**, 211 (1934); *Listy Cukrovar.*, **53**, 33 (1934).

98. Votava, *ibid.*, **55**, 365 (1937).

99. Ant-Wuorinen, *Zuntersuch. Lebensm.*, 70, 389 (1935).

100. Klostermann and Scholta, *Z. Nahr. u. Genussm.*, **31**, 67 (1916); White, *C.A.*, **24**, 3572 (1930); Bloor, *J. Biol. Chem.*, **8**, 227 (1910); Wakeman, *ibid.*, **8**, 233 (1910); Cross and Perlman, *C.A.*, **26**, 783 (1932); Krantz, *J. Assoc. Official Agri. Chem.*, **19**, 205 (1936); Reindollar, *ibid.*, **23**, 288 (1940); **20**, 161 (1937); for other color tests see Ekkert, *Pharm. Zentralhalle*, **67**, 821 (1926).

101. Feigl, Anger, and Frehden, *Mikrochemie*, **17**, 29 (1935); Vondrák, *Z. Zuckerind. Cechoslovak Rep.*, **53**, 501 (1929); Volmar, *J. pharm. chim.*, **5**, 435 (1927); Possetta and Issoglio, *Giorn. farm. chim.*, **61**, 5 (1912); Reindollar, *J. Assoc. Official Agri. Chem.*, **20**, 161 (1937); Rouzaut, *C.A.*, **31**, 8106 (1937); Vlezenbeek, *Pharm. Weekblad*, **74**, 127 (1937); Repetto, *Rev. farmaceutica*, **60**, 407 (1917); Baumann, *Z. ges. Brauw.*, **43**, 137 (1920); *Giorn. chim. ind. applicata*, **4**, 69 (1922); Poppe, *Ann. chim. anal. chem. appl.*, [2] **4**, 157 (1922); Schowalter, *Z. Nahr. u. Genussm.*, **38**, 185 (1919); Kolthoff, *Pharm. Weekblad*, **57**, 514 (1920); Rosenthaler, *Pharm. Zentralhalle*, **74**, 288 (1933); Pertusi and Di Nola, *Ann. chim. applicata*, **23**, 311 (1933); anon., *Chem. Weekblad*, **23**, 361 (1926); Dubaquie, *Ann. fals.*, **22**, 352 (1929); Pech, *Collection Czechoslovak Chem. Communications*, **6**, 126 (1934); for discussion of earlier work see Beyer, *Chem.-Ztg.*, **43**, 537 (1919); *Z. Nahr. u. Genussm.*, **6**, 861 (1903); Herzog and Kreidl, *Oesterr. Chem.-Ztg.*, **24**, 165 (1921); Bonis, *J. Chem. Soc.*, **112**, II, 430 (1917); Saláč, *Kvas*, **64**, 383 (1936); *Chem. Obzor*, **13**, 155; *C.A.*, **33**, 6520 (1939); Maes, *Bull. assoc. élèves inst. supér. fermentations Gand.*, **39**, 287 (1938); Rouzaut, *C.A.*, **31**, 8106 (1937).

102. Armstrong and Napper, *Proc. Chem. Soc.*, **16**, 160 (1900).

103. Holleman, *Rec. trav. chim.*, **40**, 446 (1921).

104. Mannessier, *Gazz. chim. ital.*, **45**, I, 540 (1915).

105. Mannessier-Mameli, *ibid.*, **65**, 51 (1935).

106. Fierz, Schlittler, and Waldmann, *Helv. Chim. Acta*, **12**, 663 (1929).

107. De Roode, *Am. Chem. J.*, **13**, 227 (1891); Holleman, *Rec. trav. chim.*, **25**, 332 (1906); **42**, 839 (1923); Remsen and Bayley, *Am. Chem. J.*, **8**, 229 (1886).

108. Blanchard, *ibid.*, **30**, 489 (1903).

109. Kreis, *Ann.*, **286**, 384 (1895).

110. Gerver, *Verslag. Wetenschappen Amsterdam*, **30**, 236 (1922).

111. Davies, *J. Chem. Soc.*, **119**, 876 (1921).

112. Reissert and Crämer, *Ber.*, **61B**, 2555 (1938).

113. Boyd and Rowe, *J. Am. Chem. Soc.*, **52**, 4959 (1930).

114. Noyes, *Am. Chem. J.*, **8**, 169 (1886).

115. Kastle, *ibid.*, **11**, 181 (1889); Remsen and Gray, *ibid.*, **19**, 500 (1897).

116. Badische Anilin- und Sodafabrik, German pat., 48,583, *Frdl.*, **2**, 544.

117. Weber, *Ber.*, **25**, 1739 (1892).

118*a*. Hall and Remsen, *Am. Chem. J.*, **2**, 133 (1880); *Ber.*, **10**, 1040 (1877). *b*. Remsen and Brown, *Am. Chem. J.*, **3**, 216 (1881). *c*. Jacobsen, *Ann.*, **206**, 168 (1881).

119. Haworth and Lapworth, *J. Chem. Soc.*, **125**, 1299 (1924).

120. Brown and Robinson, *ibid.*, **111**, 952 (1917).

121*a*. Remsen and Comstock, *Am. Chem. J.*, **5**, 108 (1883). *b*. Remsen and Stokes, *ibid.*, **6**, 262 (1884). *c*. Moulton, *ibid.*, **13**, 194 (1891). *d*. Zincke and Greune, *Ann.*, **427**, 231 (1922). *e*. Zincke and Schürmann, *Ann.*, **416**, 65 (1918).

122. Jacobsen, *Ber.*, **11**, 19 (1878); **13**, 1554 (1880); Iles and Remsen, *Ber.*, **11**, 464, 889 (1878); Remsen and Coale, *Am. Chem. J.*, **3**, 209 (1881); Remsen and Iles, *ibid.*, **1**, 122 (1879).

123. Hall and Remsen, *Ber.*, **12**, 1434 (1879); *Am. Chem. J.*, **2**, 58 (1880); Noyes and Walker, *ibid.*, **9**, 97 (1887); Weber, *Ber.*, **25**, 1740 (1892).

124. Jacobsen, *Ann.*, **206**, 180 (1881).

125. Kalcher, *Ann.*, **414**, 244 (1918); Kaufmann and Zobel, *Ber.*, **55B**, 1499 (1922).

126. Wischin, *Ber.*, **23**, 3113 (1890); Holleman, *Rec. trav. chim.*, **42**, 839 (1923); Holleman and Choufoer, *Proc. Acad. Sci. Amsterdam*, **27**, 353 (1924).

127. Choufoer, *Verslag. Akad. Wetenschappen Amsterdam*, **33**, 999 (1924); Holleman, *Anales soc. espān. fís. quím.*, **27**, 473 (1929); *C.A.*, **24**, 85 (1930).

128. Harding, *J. Soc. Chem. Ind.*, **44**, 138 (1925); see also Dominikjewicz and Kijewska, *Arch. Chem. Farm.*, **3**, 27 (1936).

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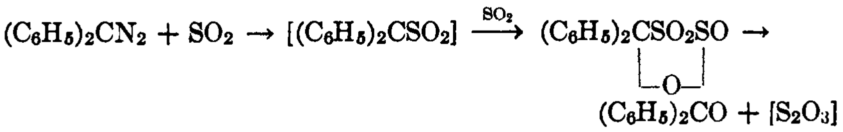
INTRODUCTION

A lively interest in the chemistry of the sulfones has been in evidence during recent years. It has been generally assumed that the sulfur-oxygen bonds of these compounds are semi-polar and that consequently the sulfur is tetracovalent. This theory is in accord with the values of the parachor[1] for a variety of monosulfones but not for sulfonal and trional which exhibit a large negative anomaly. Determination of the dipole moment values for methyl sulfone[2] in the gaseous phase, and for ethyl sulfone,[3] phenyl sulfone,[4,5] and related compounds in solution indicates an approximately tetrahedral arrangement of the valence bonds which in turn implies that the sulfur-oxygen bonds are semi-polar. The dipole moment values are large, about 4.4 Debye units for the alkyl sulfones and 5 for phenyl sulfone. That the oxygen is the negative end of the bond was demonstrated[6] for sulfoxides by measurements on *para*-substituted aryl compounds. There is no reason to believe that this is not true for sulfones. Electron diffraction measurements on methyl sulfone[7] also gave results that were best explained by the tetrahedral arrangement of the four valences.

Two attempts have been made to obtain chemical evidence for the valence angle in aryl sulfones. Maclean and Adams[8] prepared bis-(aminomesityl) sulfone but could not resolve it. Resolution might be possible if the carbon-sulfur bonds approximated the tetrahedral angle. On the other hand Lüttringhaus and Buchholz[9] in a study of the ring closure reaction of compounds having the general formula HOC_6H_4-$SO_2C_6H_4O(CH_2)_nBr$ found that the cyclic product resulted even when $n = 5$. This indicated that the two carbon-sulfur bonds might form an angle as small as 75° and not larger than 90°, compared with 112° for the sulfides. The only alternative was to assume the bonds had a small deformation energy. Thus far the evidence indicates, then, that in sulfones there exists a readily deformable approximately tetrahedral arrangement of valence bonds.

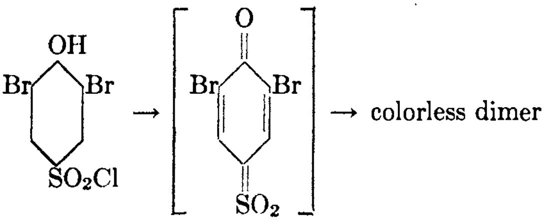
The electron diffraction measurements of Lister and Sutton[7] are incompatible with the theory that the sulfur-oxygen bonds in methyl sulfone are semi-polar and that sulfur is tetracovalent in this compound. The sulfur-oxygen bond length was found to be 1.44 ± 0.03 which is even less than the calculated value for a double bond and near that of a triple bond. A triple bond would, however, not be in accord with the dipole moment measurements since the moment of the sulfur-oxygen triple bond should be very small. From the standpoint of the electron structure of the sulfur atom its existence in the hexacovalent state in sulfones is not unreasonable, particularly since sulfur hexafluoride is known. On the other hand, hexavalent sulfur would not be expected to be tetrahedral. It may be concluded, therefore, that the nature of the sulfur-oxygen bonds in sulfones is uncertain.

It should be further mentioned that a sulfone of the structure $R_2C{=}SO_2$, containing a carbon-sulfur double bond has not been prepared. It was suggested[10] that in the reaction of sulfur dioxide with diphenyldiazomethane such a substance may be an intermediate, but it was not isolated.



$$(C_6H_5)_2CN_2 + SO_2 \rightarrow [(C_6H_5)_2CSO_2] \xrightarrow{SO_2} (C_6H_5)_2CSO_2SO \rightarrow (C_6H_5)_2CO + [S_2O_3]$$

When 3,5-dibromo-4-hydroxybenzenesulfonyl chloride is treated in acetone solution with sodium carbonate or potassium acetate there is formed an intermediate yellow product which may be a quinoidal sulfone, but here again isolation was not possible.[11]



Several other problems in sulfone chemistry are closely related to the valence behavior of sulfur. It has been observed,[12] for example, that methyl sulfone in alkaline deuterium oxide gradually exchanges its hydrogen for deuterium. This could occur through enolization and formation of a carbon-sulfur double bond or through direct ionization of the hydrogen. The same question arises in all instances where a sulfone group activates an adjacent hydrogen and facilitates a halogenation, condensation, or racemization reaction. Examples of these changes will be described later.

One of the recent developments in sulfone chemistry that is of more than usual interest has come from the investigation of the substances formed from olefinic compounds and sulfur dioxide. Simple olefins yield polymers and dienes give also cyclic unsaturated sulfones. These reactions are discussed in detail in a later section.

SIMPLE MONOSULFONES AND THEIR HALOGEN AND NITRO DERIVATIVES

In this section the alkyl, alkyl aryl, and aryl sulfones will be described. Sulfones containing other substituents and compounds containing two or more sulfone groups are taken up in later sections.

Methods of Preparation

Sulfones have been synthesized by five methods that have wide application. In addition, a number of miscellaneous reactions have been of value in particular instances. Methyl sulfone has been isolated in minute amounts from natural sources. From one ton of cattle blood[13] the amount obtained was 3.5 g. and from 1000 kg. of adrenal glands only 186 mg. was separated.[14]

Oxidation of Sulfides and Sulfoxides. Sulfones are readily prepared by the action of a variety of oxidizing agents upon the corresponding

TABLE I

Compound Oxidized	Reagent and Reference	M.P. of Sulfone, °C.	Reaction Data
	A. Alkyl and Aralkyl Sulfones		
$(CH_3)_2S$	HNO_3[1]	109 (b.p. 238)	
$CH_3SC_2H_5$	HNO_3[2]	36	
	$KMnO_4$	....	
$(C_2H_5)_2S$	HNO_3[3]	70–71 (b.p. 248)	
	$KMnO_4$[2, 5]	....	
	NaOCl[4]	....	Reaction slow in alk. sol.
	H_2O_2[6]	....	Acetic acid sol.
	Electrolysis[7]	....	Pt anode, acid sol.
$(C_2H_5)_2SO$	HNO_3[1]	....	
n-$C_3H_7SC_2H_5$	$KMnO_4$[5]	25 (b.p. 142 [23 mm.])	
$(n$-$C_3H_7)_2S$	NaOCl[4]	....	Best results in 0.2 N NaOH
	$KMnO_4$[10]	29–30	
$(n$-$C_3H_7)_2SO$	$Cl_2 + H_2O$[8]	....	
(iso-$C_3H_7)_2SO$	$KMnO_4$[2]	36	
$(n$-$C_4H_9)_2S$	HNO_3[9]	43.5	
n-$C_4H_9SC_2H_5$	H_2O_2[47]	50–50.5	
(iso-$C_4H_9)_2SO$	$KMnO_4$[2]	17 (b.p. 265)	
(iso-$C_5H_{11})_2SO$	$KMnO_4$[2]	31 (b.p. 295)	
(act-$C_5H_{11})_2SO$	$KMnO_4$[11]	29–30	Acetic acid sol.
iso-$C_5H_{11}SOC_2H_5$	$KMnO_4$[2]	13.5 (b.p. 270)	
$(n$-$C_7H_{15})_2S$	[12]	80	
$(n$-$C_8H_{17})_2S$	$HNO_3 + KMnO_4$[5]	76	
n-$C_8H_{17}SC_2H_5$	HNO_3[5]	68	
n-$C_{12}H_{25}SC_2H_5$	$KMnO_4$[56]	78.5	Acetic acid sol.
$C_{16}H_{33}SC_2H_5$	$KMnO_4$[56]	88	
$(ClCH_2)_2S$	$(C_6H_5CO)_2O_2$[13]	70.5–72	100% yield in $CHCl_3$ at 10–15°
$ClCH_2SC_2H_5$	$C_6H_5CO_3H$[67]	33 (b.p. 128 [14 mm.])	80% yield
$ClCH_2CH_2SC_2H_5$	H_2O_2[68]	(B.p. 120–122 [4 mm.])	
$(CH_3CHCl)_2S$	$(C_6H_5CO)_2O_2$[13]	78–80	
$(ClCH_2CH_2)_2S$	$(C_6H_5CO)_2O_2$[13]	55–56	
$(ClCH_2CH_2)_2SO$	$(C_6H_5CO)_2O_2$[13]	....	
$ClCH_2CH_2CH_2SC_2H_5$	H_2O_2[68]	(B.p. 160–163 [7 mm.])	
$(ClCH_2CH_2CH_2)_2S$	H_2O_2, etc.[69]	65–66	
$(BrCH_2CH_2)_2S$	$(C_6H_5CO)_2O$[13]	111–112.5	
$BrCH_2CH_2CH_2SCH_3$	$KMnO_4$[14]	34 (b.p. 156 [158 mm.])	Water solution

TABLE I (*Continued*)

Compound Oxidized	Reagent and Reference	M.P. of Sulfone, °C.	Reaction Data
		A. Alkyl and Aralkyl Sulfones (*Continued*)	
$(C_6H_5CH_2)_2S$	H_2O_2 [17]	151	Acetic acid
	$(C_6H_5CO)_2O$ [13]	149.5–151	Chloroform sol.
	CrO_3 [59]		
$(C_6H_5CH_2)_2SO$	$KMnO_4$ [16]		
	H_2O_2 [17]		
$C_6H_5CH_2SCH(CH_3)CH(CH_3)_2$	$KMnO_4$ [15]	58–59	
$C_6H_5CH_2SC_{10}H_{17}$	$KMnO_4$ [15]	127	Sulfide from camphene
$[C_6H_5(CH_3)CH]_2S$	H_2O_2 [68]	135	
$[C_6H_5(C_2H_5)CH]_2SO$	O_2(?) [62]	60	
$(C_6H_5CH_2CH_2)_2S$	H_2O_2 [64]	101	Acetic acid sol.
$(C_6H_5CH_2CH_2CH_2)_2S$	H_2O_2 [64]	117	
p-$NO_2C_6H_4CH_2SC_4H_9$-n	CrO_3 [51]	139.5	50% yield
p-$NO_2C_6H_4CH_2SC_6H_{11}$-iso	CrO_3 [51]	117	75% yield
$(p$-$CH_3C_6H_4CH_2)_2S$	$KMnO_4$ [56]	197	
		B. Alkyl Aryl Sulfones	
$C_6H_5SC_2H_5$	$KMnO_4$ [2, 18]	42	
$C_6H_5SC_3H_7$-n	H_2O_2 [57, 68]	44	Acetic acid sol.
$C_6H_5SC(CH_3)_3$	H_2O_2 [61]	98–99	
$C_6H_5SC_5H_{11}$-n	H_2O_2 [68]	31–32	
$C_6H_5SC_5H_{11}$-iso	H_2O_2 [58, 60]	35.5–36.5	
$C_6H_5SCH(C_2H_5)_2$	H_2O_2 [68]	46–47	
$C_6H_5SC(CH_3)_2C_2H_5$	H_2O_2 [61]	29–30, 72–73	
$C_6H_5SC_{10}H_{19}$ (menthyl)	$KMnO_4$ [15]	Oil	
$C_6H_5SCH_2CH_2C_6H_5$	$KMnO_4$ [15]	58	
$C_6H_5SCF_3$	CrO_3 etc.[71]	(B.p. 203–205)	
$C_6H_5SCH_2CH_2Cl$	H_2O_2 [68]	52 (b.p. 168–174 [7 mm.])	
$C_6H_5SCH_2CH_2CH_2Cl$	H_2O_2 [68, 70]	23–24, 26	
p-$ClC_6H_4SCF_3$	CrO_3, etc.[71]	55–56	
o-$ClC_6H_4SCF_3$	CrO_3, etc.[71]	(B.p. 120–123 [17 mm.])	
2,5-$Cl_2C_6H_3SCF_3$	CrO_3, etc.[71]	50	
2,4-$Cl_2C_6H_3SCF_3$	CrO_3, etc.[71]	(B.p. 128–130 [12 mm.])	
p-$BrC_6H_4SCH_3$	$KMnO_4$ [32, 56]	102.5–103	
	H_2O_2 [56]	....	
p-$BrC_6H_4SC_2H_5$	H_2O_2 [68]	56–57	
p-$BrC_6H_4SC_3H_7$-n	H_2O_2 [56]	52–53	
p-$BrC_6H_4SC_3H_7$-iso	H_2O_2 [56]	66–67	
p-$BrC_6H_4SC_4H_9$-n	H_2O_2 [56]	61	
p-$BrC_6H_4SC_4H_9$-iso	H_2O_2 [56]	49	
p-$BrC_6H_4SC_6H_{13}$-n	H_2O_2 [56]	49	

TABLE I (*Continued*)

Compound Oxidized	Reagent and Reference	M.P. of Sulfone, °C.	Reaction Data
	B. Alkyl Aryl Sulfones (*Continued*)		
p-$BrC_6H_4SCH_2C_6H_5$	H_2O_2 [56]	159	
p-$BrC_6H_4SCH_2CH_2C_6H_5$	H_2O_2 [56]	86–87	
3,4-$Br_2C_6H_3SCH_3$	H_2O_2 [19]	101	
o-$IC_6H_4SCH_3$	H_2O_2 [33]	106–107	
p-$IC_6H_4SC_2H_5$	CrO_3 [34]	83	
$C_6H_5SC(CH_3)_2CH_2NO_2$	CrO_3, H_2O_2 [53]	89–90	Acetic acid sol.
$C_6H_5SC(CH_3)_2CH(NO_2)CH_3$	CrO_3, H_2O_2 [54]	100–102	
$C_6H_5SCH_2C_6H_4NO_2$-p	CrO_3 [51]	209.5	88% yield
o-$NO_2C_6H_4SCH_3$	H_2O_2 [35]	106	
	CrO_3 [36, 52]	104–105	65%
o-$NO_2C_6H_4SC_3H_7$-n	CrO_3 [52]	50	86%
p-$NO_2C_6H_4SCH_3$	H_2O_2 [40]	141	Acetic acid sol.
	CrO_3 [51]	142.5	84% yield
p-$NO_2C_6H_4SC_2H_5$	CrO_3 [51]	138.5	76%
p-$NO_2C_6H_4SC_3H_7$-n	CrO_3 [51]	114	86%
p-$NO_2C_6H_4SC_3H_7$-iso	CrO_3 [51]	115.3	86%
p-$NO_2C_6H_4SC_4H_9$-n	CrO_3 [51]	56.4	70%
p-$NO_2C_6H_4SC_4H_9$-iso	CrO_3 [51]	73	87%
p-$NO_2C_6H_4SC_5H_{11}$-iso	CrO_3 [51]	62.5	70%
p-$NO_2C_6H_4SCH_2C_6H_5$	CrO_3 [51]	172	97%
m-$NO_2C_6H_4SCF_3$	Various [71]	(B.p. 146–148 [11 mm.])	
p-$NO_2C_6H_4SCF_3$	Various [71]	85–86	
p-$NO_2C_6H_4SCH_2CH_2Cl$	$KMnO_4$ [70]	128	
2,4-$Cl(NO_2)C_6H_3SCF_3$	Various [71]	(B.p. 170–172 [17 mm.])	
2,4-$Cl(NO_2)C_6H_3SOCF_3$	CrO_3, etc.[72]	46	
2,4,6-$Cl_2(NO_2)C_6H_2SOCF_3$	CrO_3, etc.[72]	76	
3,4,6-$Cl_2(NO_2)C_6H_2SOCF_3$	CrO_3, etc.[72]	72–73	
2,5,4-$Cl_2(NO_2)C_6H_2SOCF_3$	CrO_3, etc.[72]	60	
2,4-$(NO_2)_2C_6H_3SCH_3$	CrO_3 [41]	184	Acetic acid sol.
	$KMnO_4$ [50]	189.5	50% excess of reagent in H_2O added to sulfide in acetic acid. The yields are good. The m.p.s. are corrected.
2,4-$(NO_2)_2C_6H_3SC_2H_5$	$KMnO_4$ [50]	160	
2,4-$(NO_2)_2C_6H_3SC_3H_7$-n	$KMnO_4$ [50]	127.5	
2,4-$(NO_2)_2C_6H_3SC_3H_7$-iso	$KMnO_4$ [50]	140.5	
2,4-$(NO_2)_2C_6H_3SC_4H_9$-n	$KMnO_4$ [50]	92	
2,4-$(NO_2)_2C_6H_3SC_4H_9$-iso	$KMnO_4$ [50]	105.5	
2,4-$(NO_2)_2C_6H_3SC_5H_{11}$-n	$KMnO_4$ [50]	83	
2,4-$(NO_2)_2C_6H_3SC_5H_{11}$-iso	$KMnO_4$ [50]	95	
2,4-$(NO_2)_2C_6H_3SC_6H_{13}$-n	$KMnO_4$ [50]	97	
2,4-$(NO_2)_2C_6H_3SC_7H_{15}$-n	$KMnO_4$ [50]	101	
2,4-$(NO_2)_2C_6H_3SC_8H_{17}$-n	$KMnO_4$ [50]	98	
2,4-$(NO_2)_2C_6H_3SC_9H_{19}$-n	$KMnO_4$ [50]	92	
2,4-$(NO_2)_2C_6H_3SCH_2C_6H_5$	$KMnO_4$ [50]	182.5	
	CrO_3 [41]	177	

TABLE I (*Continued*)

Compound Oxidized	Reagent and Reference	M.P. of Sulfone, °C.	Reaction Data
B. Alkyl Aryl Sulfones (Continued)			
2,4-$(NO_2)_2C_6H_3SCH_2CH_2C_6H_5$	$KMnO_4$ [50]	133.4	
2,4-$(NO_2)_2C_6H_3SCH(CH_3)C_6H_5$	$KMnO_4$ [73]	161	
p-$CH_3C_6H_4SCH_3$	H_2O_2 [19, 47]	89	Acetic acid sol.
p-$CH_3C_6H_4SC_2H_5$	$KMnO_4$ [18]	55–56	
p-$CH_3C_6H_4SC_3H_7$-*n*	H_2O_2 [47]	....	
p-$CH_3C_6H_4SC_4H_9$-*n*	H_2O_2 [47]	(B.p. 175–177 [4 mm.])	Acetic acid sol.
p-$CH_3C_6H_4SCH_2CH_2Cl$	H_2O_2 [47]	78–78.5	
	$KMnO_4$ [48]	71	
p-$CH_3C_6H_4SCF_3$	CrO_3, etc.[71]	34–35	
3,4-$Br(CH_3)C_6H_3SCH_3$	H_2O_2 [19]	101	
m-$CF_3C_6H_4SCF_3$	CrO_3, etc.[71]	B.p. 93 (20 mm.)	
2,4-$NO_2(CH_3)C_6H_3SOCF_3$	CrO_3, etc.[72]	56	
2,4,5-$Cl(NO_2)(CH_3)C_6H_2SOCF_3$	CrO_3, etc.[72]	69	
4,6,2-$Cl(NO_2)(CH_3)C_6H_2SOCF_3$	CrO_3, etc.[72]	59	
2,4,6-$(CH_3)_3C_6H_2SCH_2CH_2Cl$	$KMnO_4$ [70]	60.5	In $MgSO_4$ sol.
C. Aryl Sulfones			
$(C_6H_5)_2S$	HNO_3 [20, 21]	128 (b.p. 379, corr.)	
	Cl_2 [30]	....	90% acetic acid sol.
	H_2O_2 [28]	....	
	CrO_3 [20, 21]	....	
	$(C_6H_5CO)_2O_2$ [13]	....	Chloroform sol.
	Electrolysis [29]	....	
$(C_6H_5)_2SO$	Cl_2 [30]	....	Acetic acid sol.
	$(C_6H_5CO)_2O_2$ [13]	....	100% yield
$(4\text{-}ClC_6H_4)_2S$	H_2O_2 [31]	148	
$(4\text{-}BrC_6H_4)_2S$	$KMnO_4$ [32]	172	
4-$IC_6H_4SC_6H_5$	CrO_3 [34]	141	
2-$NO_2C_6H_4SC_6H_5$	$KMnO_4$ [37]	....	
	H_2O_2 [67]	145	
4,2-$Cl(NO_2)C_6H_3SC_6H_5$	H_2O_2 [78]	121	
5,2-$Cl(NO_2)C_6H_3SC_6H_5$	[75]	186–187	
4-$NO_2C_6H_4SC_6H_5$	CrO_3 [51]	142	88% yield
4,2-$Cl(NO_2)C_6H_3SC_6H_3Cl_2$-2,5	H_2O_2 [76]	131	
$(2\text{-}NO_2C_6H_4)_2S$	HNO_3 [38]	....	
	CrO_3 [39]	....	
$(4\text{-}NO_2C_6H_4)_2S$	$KMnO_4$ [43]	282	Dil. sulfuric acid sol.
2,4-$(NO_2)_2C_6H_3SC_6H_5$	$KMnO_4$ [50]	161	Acetic acid sol.
4,2-$Cl(NO_2)C_6H_3SC_6H_3(NO_2)$-Cl-3,4	KNO_3 [78]	162	In H_2SO_4 sol.

TABLE I (*Continued*)

Compound Oxidized	Reagent and Reference	M.P. of Sulfone, °C.	Reaction Data
		C. Aryl Sulfones (Continued)	
$[2,4\text{-}(NO_2)_2C_6H_3]_2S$	HNO_3 [44]	240–241	Reaction at 120°
	CrO_3 [45]	....	Acetic acid sol.
$[2,4,6\text{-}(NO_2)_3C_6H_2]_2S$	CrO_3 in HNO_3 [42]	307	
$p\text{-}CH_3C_6H_4SC_6H_5$	$KMnO_4$ or CrO_3 [23]	124.5	
$p\text{-}CH_3C_6H_4SC_6H_3(NO_2)Cl\text{-}4,2$	H_2O_2 [74]	125	
$p\text{-}CH_3C_6H_5SC_6H_3(NO_2)_2\text{-}2,4$	$KMnO_4$ [50]	189.5	Acetic acid sol.
$p\text{-}CH_3C_6H_4SC_6H_3(NO_2)Cl\text{-}2,4$	H_2O_2 [74]	124	
$p\text{-}CH_3C_6H_4SC_6H_3(NO_2)Cl\text{-}2,5$	H_2O_2 [75]	189	
$4,2\text{-}(NO_2)(CH_3)C_6H_3SC_6H_5$	$KMnO_4$ [49]	104	Acetic acid
$(o\text{-}CH_3C_6H_4)_2S$	$KMnO_4$ [22]	134–135	Acetic acid
$(m\text{-}CH_3C_6H_4)_2S$	$KMnO_4$ [66]	94	40% acetic acid
$(p\text{-}CH_3C_6H_4)_2S$	$KMnO_4$ [24]	158 (b.p. 405)	In acetic acid solution
$(p\text{-}C_6H_5C_6H_4)_2S$	$KMnO_4$ [27]	....	
$p\text{-}C_6H_5C_6H_4SC_6H_3(NO_2)_2\text{-}2,4$	$KMnO_4$ [50]	170	
$(1\text{-}C_{10}H_7)_2S$	CrO_3 [26]	187	
$1\text{-}C_{10}H_7SC_6H_5$	CrO_3 [25]	99.5–100.5	
$(2\text{-}C_{10}H_7)_2S$	CrO_3 [26]	177	
$2\text{-}C_{10}H_7SC_6H_5$	CrO_3 [23, 25]	115–116	
$2\text{-}C_{10}H_7SC_{10}H_7\text{-}1$	CrO_3 [26]	122.5–123	

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[1] Saytzeff, *Ann.*, **144**, 148 (1867); see also *Ann.*, **139**, 354 (1866).

[2] Beckmann, *J. prakt. Chem.*, [2] **17**, 440 (1878).

[3] v. Oefele, *Ann.*, **127**, 370 (1863); **132**, 87 (1864).

[4] Wood and Travis, *J. Am. Chem. Soc.*, **50**, 1226 (1928).

[5] Fenton and Ingold, *J. Chem. Soc.*, 3127 (1928).

[6] Pummerer, *Ber.*, **43**, 1407 (1910).

[7] Fichter and Wenk, *Ber.*, **45**, 1376 (1912).

[8] Spring and Winssinger, *Ber.*, **16**, 329 (1883).

[9] Grabowsky, *Ann.*, **175**, 350 (1875).

[10] Winssinger, *Bull. soc. chim.*, [2] **48**, 111 (1887)

[11] Hilditch, *J. Chem. Soc.*, **93**, 1619 (1908).

[12] Winssinger, *Jahresbericht*, 1281 (1887).

[13] Levin, *J. prakt. Chem.*, [2] **118**, 282 (1928); **119**, 211 (1928); **127**, **77** (1930).

[14] Schneider, *Ann.*, **375**, 239 (1910).

[15] Posner, *Ber.*, **38**, 651 (1905).

[16] Otto and Lüders, *Ber.*, **13**, 1284 (1880).

[17] Smythe, *J. Chem. Soc.*, **101**, 2079 (1912); see also HINSBERG, *Ber.*, **41**, 2838 (1908).

[18] Otto, *Ber.*, **13**, 1275 (1880).

[19] Zincke and Frohneberg, *Ber.*, **43**, 848 (1910).

[20] Stenhouse, *Ann.*, **140**, 290 (1866).

[21] Kekulé and Szuch, *Z. Chem.*, 44 (1868).

[22] Purgotti, *Gazz. chim. ital.*, **20**, 31 (1890).

[23] Bourgeois, *Ber.*, **28**, 2323 (1895).

[24] Otto, *Ber.*, **12**, 1177 (1879).

[25] Krafft and Bourgeois, *Ber.*, **23**, 3047 (1890).

[26] Krafft, *Ber.*, **23**, 2368 (1890).

[27] Gabriel and Deutsch, *Ber.*, **13**, 387 (1880).

[28] Hinsberg, *Ber.*, **43**, 290 (1910).

[29] Fichter and Sjöstedt, *Ber.*, **43**, 3429 (1910).

[30] Böeseken and Waterman, *Rec. trav. chim.*, **29**, 325 (1910).

sulfides or sulfoxides. The reagents most commonly employed are concentrated or fuming nitric acid, potassium permanganate, hypochlorous acid or sodium hypochlorite, chromic acid, and hydrogen peroxide. The oxidation frequently stops at the sulfoxide stage when nitric acid is used. Hydrogen peroxide in acetic acid is to be highly recommended because the yields are high, the final product is easy to isolate, and groups other than the sulfide or sulfoxide are rarely attacked. Chromic acid and potassium permanganate oxidations are usually effected in acetic acid-water mixtures.

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[31] Böeseken, *ibid.*, **30**, 141 (1911).

[32] Bourgeois and Abraham, *ibid.*, **30**, 416 (1911).

[33] Zincke and Siebert, *Ber.*, **48**, 1247 (1915).

[34] Willgerodt and Klinger, *J. prakt. Chem.*, [2] **85**, 192 (1912).

[35] Claasz, *Ber.*, **45**, 1023 (1912).

[36] Schick, dissertation, Freiberg, 1906, p. 16.

[37] Bourgeois and Huber, *Bull. soc. chim.*, [4] **9**, 947 (1911); *Rec. trav. chim.*, **31**, 30 (1912).

[38] Lobry de Bruyn and Blanksma, *ibid.*, **20**, 118 (1901).

[39] Grandmougin, *Compt. rend.*, **174**, 394 (1922).

[40] Zincke and Lenhardt, *Ann.*, **400**, 16 (1913).

[41] Fromm, Benzinger, and Schafer, *Ann.*, **394**, 337 (1912).

[42] van Duin and van Lennep, *Rec. trav. chim.*, **39**, 160 (1920).

[43] Fromm and Wittman, *Ber.*, **41**, 2269 (1908).

[44] Beilstein and Kurbatow, *Ann.*, **197**, 78 (1879).

[45] Blanksma, *Rec. trav. chim.*, **20**, 425 (1901).

[46] Martynowicz, *Chem. Zentr.*, II, 1048 (1910).

[47] Gilman and Beaber, *J. Am. Chem. Soc.*, **47**, 1450 (1925).

[48] Fromm and Kohn, *Ber.*, **54**, 320 (1921).

[49] Bourgeois and Henrion, *Bull. soc. chim.*, **51**, 1416 (1932).

[50] Bost, Turner, and Norton, *J. Am. Chem. Soc.*, **54**, 1987 (1932).

[51] Waldron and Reid, *ibid.*, **45**, 2405 (1923).

[52] Foster and Reid, *ibid.*, **46**, 1944 (1924).

[53] Michael and Carlson, *J. Org. Chem.*, **5**, 1 (1940).

[54] Michael and Carlson, *ibid.*, **4**, 169 (1939).

[55] Bost and Everett, *J. Am. Chem. Soc.*, **62**, 1752 (1940).

[56] Koenigs and Wylezich, *J. prakt. Chem.*, [2] **132**, 24 (1931).

[57] Otto and Otto, *Ber.*, **21**, 998 (1888).

[58] Ipatieff and Friedman, *J. Am. Chem. Soc.*, **61**, 684 (1939).

[59] Shriner, Struck, and Jorison, *ibid.*, **52**, 2060 (1930).

[60] Otto, *Ann.*, **284**, 301 (1895).

[61] Ipatieff, Pines, and Friedman, *J. Am. Chem. Soc.*, **60**, 2732 (1938).

[62] Bermejo, Herrera, and Panizo, *Anales soc. españ. fís. quím.*, **32**, 1182 (1934); *C.A.*, **29**, 3321 (1935).

[63] Bermejo and Herrera, *C.A.*, **29**, 3321 (1935).

[64] Bermejo and Herrera, IX *Congr. intern. quim. pura aplicada*, **4**, 238 (1934); *C.A.*, **30**, 3418 (1936).

[65] Sergeev, *J. Gen. Chem. (U.S.S.R.)*, **1**, 279 (1931); *C.A.*, **26**, 2184 (1932).

[66] Bogert and Mandelbaum, *J. Am. Chem. Soc.*, **45**, 3045 (1923).

[67] Böhme, *Ber.*, 69B, 1610 (1936).

[68] Kretov and Toropova, *J. Gen. Chem. (U.S.S.R.)*, **7**, 2009 (1937); *C.A.*, **32**, 518 (1938).

[69] Bennett and Hock, *J. Chem. Soc.*, **127**, 2671 (1925).

[70] Baddeley and Bennett, *ibid.*, 46 (1933).

[71] Müller, Scherer, and Schumacher, U. S. pat., 2,108,606; *C.A.*, **32**, 2958 (1938); French pat., 820,796, *C.A.*, **32**, 3422 (1938); British pat., 479,774, *C.A.*, **32**, 5226 (1939).

[72] Schumacher, Scherer, and Müller, U. S. pat., 2,191,062; *C.A.*, **34**, 4588 (1940); French pat., 844,321, *C.A.*, **34**, 7300 (1940); British pat., 503,920, *C.A.*, **33**, 7586 (1939).

[73] Kharasch, May, and Mayo, *J. Org. Chem.*, **3**, 188 (1938).

[74] Loudon and Robson, *J. Chem. Soc.*, 242 (1937).

[75] Loudon, *ibid.*, 902 (1939).

[76] Loudon and Shulman, *ibid.*, 1618 (1938).

In Table I are listed the simple alkyl, alkyl aryl, and aryl sulfones together with their halogen and nitro derivatives which have been prepared by oxidation methods. Sulfones containing other substituents are discussed in later sections.

Alkylation and Arylation of Sulfinates. A second method for preparing sulfones which has wide application involves the reaction of an alkali or silver sulfinate with an alkyl halide or, rarely, an alkyl potassium sulfate. Halogen compounds as diverse as methyl iodide, *tert*-amyl bromide, and triphenylmethyl chloride have been used successfully. Aryl halides containing one or more nitro groups *ortho* or *para* to the halogen are also sufficiently reactive to give fair yields of sulfones. When two halogens are attached to the same carbon as in methylene iodide only one of them is replaceable by a sulfone group. Any further reaction that may occur results in oxidation of the sulfinate.

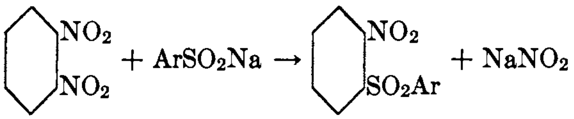
$$C_6H_5SO_2Na + CH_2ISO_2C_6H_5 + H_2O \rightarrow C_6H_5SO_3H + NaI + CH_3SO_2C_6H_5$$

Chloroform does not react while benzotrichloride gives a monosulfone in small yield. The trichloroethanes yield disulfones; their behavior is discussed under γ-disulfones (see p. 743).

$$C_6H_5CCl_3 + 2C_6H_5SO_2Na + H_2O \rightarrow C_6H_5CH_2SO_2C_6H_5 + 2HCl + NaCl + C_6H_5SO_3Na$$

The use of halogen derivatives of aliphatic oxygen and nitrogen-containing compounds is described in later sections. With these limitations Table II contains data for the sulfones that have been prepared by alkylation or arylation of sulfinates.

Closely related to the preparations of Table II *C*, is the reaction of an alkali sulfinate with an *o*-dinitro compound.[15]



The sulfones made by this reaction are listed in Table III.

TABLE II

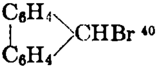
Sulfinate	Halide or Sulfate and Reference	M.P. of Sulfone, °C.	Reaction Notes
A. Alkyl Sulfones			
$C_2H_5SO_2Na$	C_2H_5Br [2]	73–74	
	p-$NO_2C_6H_4CH_2Br$ [38]	133–134	In alcohol, 24 hrs., reflux
$(CH_3)_3CSO_2Ag$	CH_3I [37]	78–79	
$C_6H_5CH_2SO_2Na$	CH_3I [1]	127	In water sol.
	C_2H_5I [1]	84	
	$C_6H_5CH_2Cl$ [2]	150	In alcohol sol.
B. Aryl Alkyl[43] *and Aralkyl Sulfones*			
CH_3SO_2Na	2,4-$(NO_2)_2C_6H_3Cl$ [28]	187	In aqueous alcohol sol.
$C_2H_5SO_2Na$	2,4-$(NO_2)_2C_6H_3Cl$ [28]	157	
$C_6H_5CH_2CH_2SO_2Na$	2,4-$(NO_2)_2C_6H_3Cl$ [44]	131	Alcohol sol.
$C_6H_5SO_2Na$	CH_3I [3]	88	In alcohol sol. at 100°
	CH_3KSO_4 [6]	....	At 120–130° in water sol.
	C_2H_5Br [2]	41 (b.p. 300°)	....
	n-C_3H_7Br [4]	44	....
	iso-C_3H_7Br [4]	< -10	....
	$(CH_3)_2CBrCH_2CH_3$ [5]	70	In alcohol sol.
	iso-$C_5H_{11}KSO_4$ [6]	37	In H_2O, 150°
	$CH_2{=}CHCH_2Br$ [7]	Oil	....
	$ClCH_2NO_2$ [30]		Poor yield
	$C_6H_5CH_2Cl$ [33, 34]	146–146.5	In 100% alcohol
	o-$NO_2C_6H_4CH_2Cl$ [30]	113	Alcohol sol.
	m-$NO_2C_6H_4CH_2Cl$ [30]	163	
	p-$NO_2C_6H_4CH_2Cl$ [30]	207	
	p-$NCC_6H_4CH_2Cl$ [31]	204.5	In alcohol sol.
	$(C_6H_5)_3CCl$ [23]	175–176	In ether sol.
	$(C_6H_5)_2(p$-$O_2NC_6H_4)$-CCl [24]	167–168	....
	CH_2Cl_2 [13, 35]	52–53	In alcohol sol.; one Cl reacts
	CH_2Br_2 [35]	46–48	In alcohol sol.; one Br reacts
	CH_2I_2 [3]	64.5	In alcohol sol.; one I reacts
	CH_3CHCl_2 [13, 35]	52	In alcohol, 150–160°; one Cl reacts; yield small
	$C_6H_5CHCl_2$ [35]	....	Yield small
	$C_6H_5CCl_3$ [35]	147	$C_6H_5CH_2SO_2C_6H_5$ is formed
	p-$NCC_6H_4CHCl_2$ [33]	162.5–163.5	In alcohol, 100°; one Cl reacts

TABLE II (*Continued*)

Sulfinate	Halide or Sulfate and Reference	M.P. of Sulfone, °C.	Reaction Notes
B. Aryl Alkyl and Aralkyl Sulfones (Continued)			
4-$FC_6H_4SO_2Na$	p-$NO_2C_6H_4CH_2Cl$[39]	185	In water-alcohol mixture
4-$ClC_6H_4SO_2Na$	CH_3I[27, 42]	57–58, 96	In hot alcohol, 14 to 20 hrs.
	C_2H_5Br[27]	(260–261?)	
	iso-C_3H_7Br[27]	(226–227?)	
	$C_6H_5CH_2Cl$[27]	257–258	
	p-$O_2NC_6H_4CH_2Cl$[30]	162	In boiling alcohol sol.
	m-$O_2NC_6H_4CH_2Cl$[30]	179	
	o-$O_2NC_6H_4CH_2Cl$[30]	137	
	p-$NCC_6H_4CH_2Cl$[31]	148.5	
2,5-$Cl_2C_6H_3SO_2Na$	CH_3I	88	
p-$BrC_6H_4SO_2Na$	p-$O_2NC_6H_4CH_2Cl$[30]	195	
	m-$O_2NC_6H_4CH_2Cl$[30]	182	
	o-$O_2NC_6H_4CH_2Cl$[30]	137	
o-$IC_6H_4SO_2Na$	CH_3I[41]	109	
p-$IC_6H_4SO_2Na$	p-$O_2NC_6H_4CH_2Cl$[30]	223.5	
	m-$O_2NC_6H_4CH_2Cl$[30]	218	In boiling alcohol sol.
	o-$O_2NC_6H_4CH_2Cl$[30]	129	
2-$O_2NC_6H_4SO_2Ag$	CH_3I[18]	102	
3-$O_2NC_6H_4SO_2Na$	$C_6H_5CH_2Cl$[30, 46, 47]	160, 151–152	In alcohol sol.
	p-$O_2NC_6H_4CH_2Cl$[30, 46]	192, 180–181	
	m-$O_2NC_6H_4CH_2Cl$[30, 46]	171, 194–195	In boiling alcohol sol.
	o-$O_2NC_6H_4CH_2Cl$[30, 46]	184, 192–193	
4-$O_2NC_6H_4SO_2Ag$	CH_3I[19]	141	
2,4-$O_2N(Cl)C_6H_3SO_2Ag$	CH_3I[20]	143	
2-$CH_3C_6H_4SO_2Na$	CH_3I[8]	Yellow oil	In alcohol at 100°
	C_2H_5Br[8]	Yellow oil	In alcohol for 20 hrs.
	n-C_3H_7Br[8]	Oil	
	iso-C_3H_7Br[8]	Oil	
	n-C_4H_9Br[8]	Oil	
	iso-C_4H_9Br[8]	Oil	In alcohol sol.
	n-$C_5H_{11}Br$[8]	Yellow-brown oil	
	sec-$C_6H_{13}Br$[8]	Oil	
	n-$C_{18}H_{37}I$[8]	65°	
p-$CH_3C_6H_4SO_2Na$	CH_3I[9]	86–87	
p-$CH_3C_6H_4SO_2K$	CH_3KSO_4[6]	....	In water sol.
p-$CH_3C_6H_4SO_2Na$	C_2H_5Br[2]	56	In alcohol sol.
	n-C_3H_7Br[10]	53	
	n-$C_3H_7NaSO_4$[11]	....	In water, 120–130°
	n-$C_{12}H_{25}NaSO_4$[36]	....	In water sol.
	$CH_2{=}CHCH_2Br$[7]	52–53	Alcohol sol.

TABLE II (*Continued*)

B. Aryl Alkyl and Aralkyl Sulfones (*Continued*)

Sulfinate	Halide or Sulfate and Reference	M.P. of Sulfone, °C.	Reaction Notes
	m-$O_2NC_6H_4CH_2Cl$ [30, 45]	162	
	o-$O_2NC_6H_4CH_2Cl$ [30, 45]	182, 131–132	In boiling alcohol sol.
	p-$O_2NC_6H_4CH_2Cl$ [45]	188–189	
	2,4-$(O_2N)_2C_6H_3CH_2Cl$ [45]	159–160	80–85% yield
	p-$NCC_6H_4CH_2Cl$ [31]	211	
	$(C_6H_5)_3CCl$ [25]	173	In benzene sol.
	 $\begin{matrix}C_6H_4\\ \vert \\ C_6H_4\end{matrix}\!>CHBr$ [40]	224–225	In alcohol 24 hrs.
	CH_2Cl_2 [35]	84	One Cl reacts
	CH_2Br_2 [35]	90–92	One Br reacts
	CH_2I_2 [12]	126	One I reacts
	CH_3CHCl_2 [13, 35]	84	One Cl reacts, poor yield
	$C_6H_5CHCl_2$ [35]	203	One Cl reacts; poor yield
2,5,4-$Cl(NO_2)(CH_3)$-$C_6H_2SO_2Na$	CH_3I [29]	145–146	
2,4-$(CH_3)_2C_6H_3SO_2Na$	CH_3I [14]	55	In methanol sol.
	C_2H_5Br [14]	53	In alcohol sol.
	n-C_3H_7Br [14]	68–69	
	$CH_2{=}CHCH_2Br$ [15]	Oil	
1-$C_{10}H_7SO_2Na$	CH_3I [16]	102–103	
	C_2H_5I [16]	88–89	
	p-$NCC_6H_4CH_2Cl$ [31]	162.5	
2-$C_{10}H_7SO_2Na$	CH_3I [16]	142–143	
	C_2H_5Br [16]	43–45	
	$CH_2{=}CHCH_2Br$ [17]	95	
1,2-$ClC_{10}H_6SO_2Ag$	CH_3I[22]	139–140	

C. Aryl Sulfones

Sulfinate	Halide or Sulfate and Reference	M.P. of Sulfone, °C.	Reaction Notes
$C_6H_5SO_2Na$	2-$O_2NC_6H_4Cl$ [21]	147.5	
	4-$O_2NC_6H_4Cl$ [21, 48]	143	In aqueous alcohol
	2,4-$(O_2N)_2C_6H_3Cl$ [28]	159–160	In aqueous alcohol
	2,4,6-$(O_2N)_3C_6H_2Cl$ [21]	233	
p-$ClC_6H_4SO_2Na$	2,4-$(O_2N)_2C_6H_3Cl$ [28]	168	Aqueous alcohol. 10–20 minutes
	2,4,6-$(O_2N)_3C_6H_2Cl$ [27]	104–105	In alcohol, 20 hrs.
p-$BrC_6H_4SO_2Na$	2,4-$(O_2N)_2C_6H_3Cl$ [28]	190	Aqueous alcohol, 10–20 minutes
p-$CH_3CONHC_6H_4SO_2K$	2-$O_2NC_6H_4Br$ [48]	?	Cyclohexanol sol.
	4-$O_2NC_6H_4Br$ [48]	?	Cyclohexanol sol.

TABLE II (*Continued*)

Sulfinate	Halide or Sulfate and Reference	M.P. of Sulfone, °C.	Reaction Notes
	C. Aryl Sulfones (*Continued*)		
m-$O_2NC_6H_4SO_2Na$	2,4-$(O_2N)_2C_6H_3Cl$ [28]	196–197	In alcohol, 15 min.
2,5-$Cl_2C_6H_3SO_2Na$	2,4-$(O_2N)_2C_6H_3Cl$ [28]	178	In alcohol sol.
o-$CH_3C_6H_4SO_2Na$	2,4-$(O_2N)_2C_6H_3Cl$ [28]	154	In aqueous alcohol
p-$CH_3C_6H_4SO_2Na$	4,2-$Cl(O_2N)C_6H_3Cl$ [46]	124	In ethylene glycol
	2,4-$(O_2N)_2C_6H_3Cl$ [28]	187	In aqueous alcohol
2-$C_{10}H_7SO_2NH_4$	2,4-$(O_2N)_2C_6H_3Cl$ [26]	228	In alcohol sol.
	2,4-$Cl(O_2N)C_6H_3Cl$ [46]	125	In ethylene glycol

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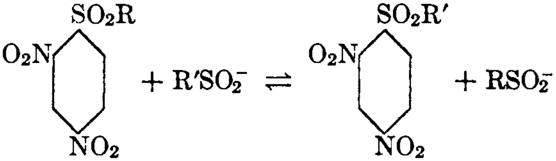
[1] Fromm and de Seixas Palma, *Ber.*, **39**, 3315 (1906).
[2] Otto, *Ber.*, **13**, 1277 (1880).
[3] Michael and Palmer, *Am. Chem. J.*, **6**, 254 (1885).
[4] R. Otto and W. Otto, *Ber.*, **21**, 998 (1888).
[5] Posner, *Ber.*, **38**, 651 (1905).
[6] Otto, *Ann.*, **284**, 301 (1895).
[7] Otto, *Ann.*, **283**, 184 (1894).
[8] Tröger und Voigtländer-Tetzner, *J. prakt. Chem.*, [2] **54**, 524 (1896).
[9] Otto, *Ber.*, **18**, 161 (1885).
[10] Otto, *J. prakt. Chem.*, [2] **40**, 562 (1889).
[11] Tröger and Uhde, *ibid.*, [2] **59**, 335 (1899).
[12] Otto, *Ber.*, **21**, 655 (1888).
[13] Otto, *J. prakt. Chem.*, [2] **40**, 515 (1889).
[14] Tröger and Budde, *ibid.*, [2] **66**, 149 (1902).
[15] Tröger and Hille, *ibid.*, [2] **68**, 310 (1903).
[16] Otto, Rössing, and Tröger, *ibid.*, [2] **47**, 102 (1893).
[17] Tröger and Artmann, *ibid.*, [2] **53**, 500 (1896).
[18] Zincke and Farr, *Ann.*, **391**, 74 (1912).
[19] Zincke and Lenhardt, *Ann.*, **400**, 16 (1913).
[20] Zincke and Baeumer, *Ann.*, **416**, 99 (1918).
[21] Ullmann and Pasdermadjian, *Ber.*, **34**, 1153 (1901).
[22] Zincke and Eismayer, *Ber.*, **51**, 758 (1918).
[23] Baeyer and Villiger, *Ber.*, **36**, 2789 (1903).
[24] Baeyer and Villiger, *Ber.*, **37**, 608 (1904).
[25] Meyer and Fischer, *J. prakt. Chem.*, [2] **82**, 525 (1910).
[26] Grandmougin, *Compt. rend.*, **174**, 393 (1922).
[27] Purgotti, *C.A.*, **13**, 2515 (1919).
[28] Loudon, *J. Chem. Soc.*, 537 (1935).
[29] Dann and Davies, *ibid.*, 1050 (1929).
[30] Tröger and Nolte, *J. prakt. Chem.*, [2] **101**, 136 (1920).
[31] Tröger and Beck, *ibid.*, **87**, 289 (1913).
[32] Tröger and Mueller, *Arch. Pharm.*, **252**, 32 (1914).
[33] Otto and Otto, *Ber.*, **21**, 1696 (1888).
[34] Shriner, Struck, and Jorison, *J. Am. Chem. Soc.*, **52**, 2060 (1930).
[35] Otto, *J. prakt. Chem.*, [2] **40**, 527 (1889).
[36] Henkel and Cie G.m.b.H., British pat., 415,527, *C.A.*, **29**, 820 (1935).
[37] Rheinboldt, Mott, and Molzkus, *J. prakt. Chem.*, [2] **134**, 257 (1932).
[38] Blackburn and Challenger, *J. Chem. Soc.*, 1872 (1938).
[39] Hann, *J. Am. Chem. Soc.*, **57**, 2167 (1935).
[40] Adickes, *J. prakt. Chem.*, [2] **145**, 235 (1936).
[41] Barber and Smiles, *J. Chem. Soc.*, 1141 (1928).
[42] Miller and Smiles, *ibid.*, **127**, 224 (1925).
[43] For mention of higher alkyl aryl sulfones without specific data see British pat., 415,877, *C.A.*, **29**, 858 (1935).

TABLE III

Nitro Compound	Alkali Sulfinate	Sulfone, M.P., °C.
o-$C_6H_4(NO_2)_2$	p-$CH_3C_6H_4SO_2Na$	156–157
	p-$ClC_6H_4SO_2Na$	137–138
	p-$CH_3OC_6H_4SO_2Na$	149.5
	3,4,5-$CH_3(OH)(COOH)C_6H_2SO_2Na$	226–227 (dec.)
1,3,4-$ClC_6H_3(NO_2)_2$	p-$CH_3C_6H_4SO_2Na$	191
	$C_6H_{11}SO_2Na$	168–169
1,2,4,5-$Cl_2C_6H_2(NO_2)_2$	p-$CH_3C_6H_4SO_2Na$	167

In a somewhat analogous manner one sulfone group and its attached radical may be replaced by another if nitro groups are situated *ortho* and *para* to the first.[16a]



Since the reaction is reversible the extent to which a change occurs depends upon the relative stabilities and concentrations of the competing anions (sulfinates). Exchange of the sulfone groups occurs readily for the following pairs of compounds. In these replacement reactions three moles of alkali sulfinate were heated with one mole of the dinitro sulfone in aqueous alcohol.

2,4-$(O_2N)_2C_6H_3SO_2CH_3$ reacts with $C_2H_5SO_2Na$.

2,4-$(O_2N)_2C_6H_3SO_2C_2H_5$ reacts with CH_3SO_2Na and p-$CH_3C_6H_4SO_2Na$

2,4-$(O_2N)_2C_6H_3SO_2C_6H_5$ reacts with CH_3SO_2Na, $C_2H_5SO_2Na$, and p-$CH_3C_6H_4SO_2Na$.

2,4-$(O_2N)_2C_6H_3SO_2C_6H_4CH_3$-$p$ reacts with $C_2H_5SO_2Na$ and $C_6H_5SO_2Na$.

2,4-$(O_2N)_2C_6H_3SO_2C_6H_4Cl$-$p$ reacts with $C_6H_5SO_2Na$.

2,4-$(O_2N)_2C_6H_3SO_2C_6H_4NO_2$-$m$ reacts with p-$CH_3C_6H_4SO_2Na$.

2,4-$(O_2N)_2C_6H_3SO_2C_6H_3(NO_2)Cl$-3,4 reacts with p-$ClC_6H_4SO_2Na$.

2,4-$(O_2N)_2C_6H_3SO_2C_6H_3(NO_2)Br$-3,4 reacts with p-$BrC_6H_4SO_2Na$.

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[44] Kharasch, May, and Mayo, *J. Org. Chem.*, **3**, 175 (1938).

[45] Shriner and Greenlee, *ibid.*, 4, 247 (1939).

[46] Loudon and Robson, *J. Chem. Soc.*, 242 (1937).

[47] Chatterjee and Robinson, *ibid.*, 2780 (1927).

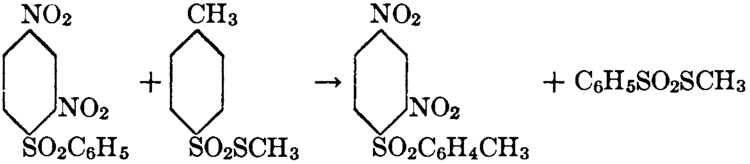
[48] Roblin, Williams, and Anderson, *J. Am. Chem. Soc.*, **63**, 1933 (1941); Roblin, U. S. pat., 2,227,400, *C.A.*, **35**, 2531 (1941). Many sulfones were made but not purified for analysis.

On the other hand these pairs of compounds do not react.

2,4-$(O_2N)_2C_6H_3SO_2C_6H_5$ did not react with 2,5-$Cl_2C_6H_3SO_2Na$.

2,4-$(O_2N)_2C_6H_3SO_2C_6H_3(NO_2)Cl$-3,4 did not react with *m*-$O_2NC_6H_4SO_2Na$.

Interchange of sulfone groups also occurs when the dinitrosulfone reacts with a thiosulfonate in the presence of sodium carbonate.



Friedel-Crafts Reaction. A third method for preparing sulfones consists in the reaction of a sulfonyl halide with an aromatic hydrocarbon in the presence of aluminum chloride or ferric chloride. This method is limited to the synthesis of alkyl aryl and aryl sulfones, and only for the latter are the yields good. The mechanism of the reaction has been thoroughly investigated. *p*-Bromobenzenesulfonyl chloride forms an addition product with aluminum chloride in carbon disulfide solution.[17] With a trace of benzene this becomes converted largely into *p*-bromobenzenesulfinic acid. With an equivalent amount or more of benzene some of the sulfinic acid still results although sulfone formation is the main reaction. When the sulfonyl bromide is substituted for the chloride the following reaction occurs.

$$p\text{-}BrC_6H_4SO_2Br + AlBr_3 \longrightarrow p\text{-}BrC_6H_4SO_2AlBr_2 + Br_2$$

No sulfone can be obtained by adding benzene. Dilution of the reaction mixture with water re-forms the sulfonyl bromide.

$$ArSO_2AlBr_2 + Br_2 \longrightarrow ArSO_2Br + AlBr_3$$

By analogy conversion of a sulfonyl chloride into a sulfinic acid by aluminum chloride should give free chlorine. Actually chlorination products were isolated.

A sulfonyl chloride reacts with benzene only when present as an addition product of aluminum chloride. The activity of this addition product is much increased by the presence of free aluminum chloride in the solution. Since the resulting sulfone forms an inactive addition product with aluminum chloride it is necessary to employ at least one mole of catalyst per mole of sulfone produced. The relative reaction rates of the *p*-bromobenzenesulfonyl chloride-aluminum chloride addition product with various compounds for one set of conditions are shown in Table IV. Nitrobenzene gives a crystalline addition product

TABLE IV

REACTIONS OF p-$BrC_6H_4SO_2Cl$

Compound	K
$C_6H_5CH_3$	0.00413
C_6H_6	0.00111
C_6H_5Br	0.00102
C_6H_5Cl	0.000802
$C_6H_5NO_2$	0.000000

with aluminum chloride but does not react with the sulfonyl chloride.

The velocity constants for various sulfonyl chlorides in the reaction with benzene in excess benzene as the solvent[18] are listed in Table V.

TABLE V

REACTIONS OF AROMATIC SULFONYL CHLORIDES WITH BENZENE

	K for	
Compound	0.1 N sol.	0.2 N sol.
p-$CH_3C_6H_4SO_2Cl$	0.000646	....
$C_6H_5SO_2Cl$	0.00212	0.00382
p-$IC_6H_4SO_2Cl$	0.00140	0.00285
p-$BrC_6H_4SO_2Cl$	0.00111	0.00226
p-$ClC_6H_4SO_2Cl$	0.00106	0.00224
m-$O_2NC_6H_4SO_2Cl$	0.000136	0.000284

The reaction of benzene with benzenesulfonyl chloride has also been investigated in benzenesulfonyl chloride solution.[19] Here the benzenesulfonyl chloride-aluminum chloride complex did not form as it does in benzene solution.

In Table VI are given the essential data for the reactions in which a variety of sulfones have been prepared by the Friedel-Crafts method.

The reaction of benzenesulfonyl chloride with naphthalene in the presence of aluminum chloride gives no more than a trace of a crystalline product.[20a] No sulfone was isolated from the reaction of m-benzenedisulfonyl chloride and benzene, amorphous products constituting the reaction mixture. Ferric chloride[20b] has been patented as a catalyst for the preparation of sulfones.

Sulfones from Sulfonic Acids. In the section on sulfonation reactions it was pointed out that sulfones frequently occur as by-products in the preparation of sulfonic acids. It is interesting in this connection that phenyl sulfone has been found in some samples of thiophene-free benzene,[21] apparently because of its formation in the purification process involving sulfuric acid. Likewise the still residue from the preparation of phenol by the action of fused alkali with sodium benzenesulfonate was shown to be about one-third phenyl sulfone.[22]

TABLE VI

SULFONYL CHLORIDE	HYDROCARBON OR DERIVATIVE, REF.	M.P. OF SULFONE. °C.	REACTION NOTES
CH_3SO_2Cl	C_5H_6 [14]	88	Excess benzene, poor yield
$C_6H_5SO_2Cl$	C_6H_6 [1, 21]	124, 122.5–123.5	80% yield
	C_6H_5Cl [1, 7b, 15, 21]	93, 91–91.5	87% yield
	C_6H_5Br [1]	....	No reaction
	$C_6H_5N(CH_3)_2$ [13]	178	In CS_2
	$C_6H_5CH_3$ [1, 21]	124–125, 125–125.5	*Para* compound
	o-$CH_3OC_6H_4CH_3$ [20]	112–112.5	
	$C_6H_5C_2H_5$ [21]	93–93.5	
	m-$C_6H_4(CH_3)_2$ [1]	80	4-sulfone
	m-$C_6H_4(C_6H_5)_2$ [23]	119	Poor yield
p-$ClC_6H_4SO_2Cl$	C_6H_6 [6, 7a]	93	In excess benzene
	C_6H_5Cl [2, 4]	147	89% yield
p-$BrC_6H_4SO_2Cl$	C_6H_6 [4, 7a, 21]	108–108.5, 104–105	In excess benzene
	C_6H_5Cl [4, 5]	157	*Para* compound
	C_6H_5Br [4, 5, 16, 21]	172, 170–171	*Para* compound
	$C_6H_5CH_3$ [4, 5]	130.5	*Para* compound
p-$IC_6H_4SO_2Cl$	C_6H_6 [6, 7a, 17]	141	In CS_2 sol. 80–90% yield
	$C_6H_5CH_3$ [11]	162	At 0°, *para* compound
	p-$C_6H_4(CH_3)_2$ [11]	115	
p-$CH_3C_6H_4SO_2Cl$	o-$CH_3OC_6H_4CH_3$ [20]	126	
m-$NO_2C_6H_4SO_2Cl$	C_6H_6 [7a]	80.5–81	In benzene at 40°
	$C_6H_5CH_3$ [18]	93	Low yield
4,3-$Cl(NO_2)C_6H_3SO_2Cl$	C_6H_5Cl [24]	130	
o-$CH_3C_6H_4SO_2Cl$	C_6H_6 [9, 10]	81	95% yield
m-$CH_3C_6H_4SO_2Cl$	$C_6H_5CH_3$ [12]	116	*Para* compound
p-$CH_3C_6H_4SO_2Cl$	C_6H_6 [3, 6, 7a, 19]	124.5	Excess benzene
	C_6H_5Cl [21]	123–123.5	
	C_6H_5Br [21]	135–136	
	$C_6H_6N(CH_3)_2$ [13]	212	In CS_2
	$C_6H_5CH_3$ [1, 4, 5, 21]	158, 156–158	85% yield
	$C_6H_6C_2H_5$ [21]	112–113	
3,4-$CH_3(CH_3O)C_6H_3SO_2Cl$	C_6H_6 [20]	112–112.5	
	$C_6H_5OCH_3$ [20]	126	Isomer, m.p. 102°
	o-$CH_3OC_6H_4CH_3$ [20]	138	In CS_2 sol.
2,5-$CH_3(NO_2)C_6H_3SO_2Cl$	C_6H_6 [8, 9]	158	At b.p. of benzene
4,3-$CH_3(NO_2)C_6H_3SO_2Cl$	C_6H_6 [25]	117.5	93% yield
2,4,6-$(CH_3)_3C_6H_2SO_2Cl$	1,3,5-$(CH_3)_3C_6H_3$ [22]	202–204 (corr.)	In CS_2; 75% yield
p-$C_6H_5C_6H_4SO_2Cl$	$C_6H_5C_6H_5$ [26]	216	

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[1] Beckurts and Otto, *Ber.*, **11**, 2066 (1878).

[2] Ullmann and Korselt, *Ber.*, **40**, 641 (1907).

[3] Michael and Adair, *Ber.*, **11**, 116 (1878).

[4] Böeseken, *Rec. trav. chim.*, **30**, 139 (1911).

[5] Olivier, *ibid.*, **33**, 161 (1914).
[6] Olivier, *ibid.*, **33**, 249 (1914).
[7] (*a*) Olivier, *ibid.*, **35**, 112, 170 (1916); (*b*) *Ibid.*, **35**, 170 (1916).
[8] Norris, *Am. Chem. J.*, **24**, 475 (1900).
[9] Ullmann and Lehner, *Ber.*, **38**, 734 (1905).
[10] Weedon and Doughty, *Am. Chem. J.*, **33**, 418 (1905).
[11] Willgerodt and Plockstíes, *J. prakt. Chem.*, [2] **85**, 199 (1912).
[12] Witt and Uerményi, *Ber.*, **46**, 306 (1913).
[13] Gebauer-Fülnegg and Schwarz, *Ber.*, **61B**, 1307 (1928).
[14] Böeseken and van Ockenburg, *Rec. trav. chim.*, **33**, 321 (1914).
[15] Haehl, *Compt. rend.*, **177**, 194 (1923).
[16] Böeseken and Waterman, *Rec. trav. chim.*, **29**, 324 (1910).
[17] Willgerodt and Klinger, *J. prakt. Chem.*, [2] **85**, 198 (1912).
[18] Limpricht, *Ann.*, **278**, 257 (1894).
[19] Newell, *Am. Chem. J.*, **20**, 303 (1898).
[20] Kolhatkar and Bokil, *J. Indian Chem. Soc.*, **7**, 843 (1930).
[21] Buehler and Masters, *J. Org. Chem.*, **4**, 262 (1939).
[22] Maclean and Adams, *J. Am. Chem. Soc.*, **55**, 4683 (1933).
[23] Goodman and Lowry, *ibid.*, **60**, 2155 (1938).
[24] Loudon and Robson, *J. Chem. Soc.*, 242 (1937).
[25] Chardonnens and Venetz, *Helv. Chim. Acta*, **22**, 853 (1939).
[26] Kuczyński, Kuczyński, and Sucharda, *Roczniki Chem.*, **18**, 625 (1938); *C.A.*, **34**, 3246 (1940).

Apparently most of the trace of sulfone originally present survives the alkali treatment.

In some sulfonations the yield of sulfone becomes appreciable. *p*-Dichlorobenzene[23] with 10% oleum gives 10–15% of the sulfone. Fluorobenzene, *o*-dichlorobenzene, *o*-dibromobenzene, and iodobenzene[24] with chlorosulfonic acid at 50° give chiefly the sulfones and in other instances with this reagent sulfone formation is a common side reaction.[25] Fluorosulfonic acid gives only a trace of sulfone with ethylbenzene.[26] The action of chlorosulfonic anhydride, $S_2O_5Cl_2$, upon toluene gives a chlorotolyl tolyl sulfone as one product.[27]

By varying the reaction conditions a sulfone may be made the chief product of a sulfonation reaction provided the original compound does not contain a *meta*-directing group or an accumulation of other groups which renders sulfonation difficult. The reaction between a sulfonic acid and an aromatic compound proceeds much less readily than does the reaction with sulfuric acid. To make the sulfone formation occur it is necessary to keep the reaction mixture anhydrous by removing the water as fast as it is formed either by distillation or by chemical

$$C_6H_5SO_3H + C_6H_6 \rightarrow (C_6H_5)_2SO_2 + H_2O$$

means. Both types of procedure are illustrated in the following paragraphs.

A fair yield of phenyl sulfone results from the action of sulfur trioxide upon excess benzene,[28] preferably in the vapor phase,[29] part of the sulfonating agent reacting with the water. It has been suggested[30] that sulfur trioxide reacts in the bimolecular form in producing sulfones but there is no direct evidence on this point.

$$2C_6H_6 + S_2O_6 \rightarrow (C_6H_5)_2S(OH)_2O_2SO_2 \rightarrow (C_6H_5)_2SO_2 + H_2SO_4$$

Instead of the sulfonating agent removing the water formed in the reaction, phosphorus pentoxide may be used, since heating a sulfonic acid with a hydrocarbon in the presence of this reagent yields a sulfone.[31]

When excess benzene is refluxed with sulfuric acid and the condensed hydrocarbon is passed through an automatic separator to remove the water, the yield of phenyl sulfone reaches 75–80% in 50 hours.[32] Toluene, chlorobenzene, bromobenzene, and naphthalene[31b] give the corresponding sulfones in a similar manner.

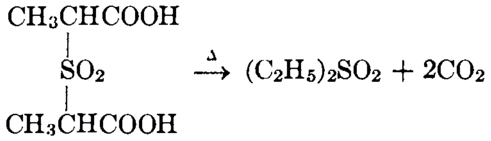
Unsymmetrical sulfones can be prepared by passing a gaseous hydrocarbon through a sulfonic acid[33] at temperatures in the range of 125–200°. The excess hydrocarbon vapor removes the water. This useful method of sulfone formation is illustrated by the data of Table VII taken from the work of Meyer.[33]

TABLE VII

Sulfonic Acid	Hydrocarbon (or Derivative)	Reaction Temp. °C. and Time	Yield and M.P. of Sulfone, °C.
$C_6H_5SO_3H$	C_6H_6	150, 15 hrs.	30%; 128
	$C_6H_5CH_3$	135, 8 hrs.	High; 80
	$1,2,4\text{-}(CH_3)_3C_6H_3$	150, 4 hrs.	. . . .; 160
	$1,3,5\text{-}(CH_3)_3C_6H_3$	160, 15 hrs.	. . . .
	C_6H_5Cl	160, 20 hrs.	High; 91
$p\text{-}CH_3C_6H_4SO_3H$	C_6H_6	135, 8 hrs.	High; 80
	$C_6H_5CH_3$	180, 20 hrs.	80%; 158
	C_6H_5Cl	160, 20 hrs.	High; 128
$2,4\text{-}(CH_3)_2C_6H_3SO_3H$	$C_6H_5CH_3$	170, 24 hrs.	. . . .; 121
	$m\text{-}C_6H_4(CH_3)_2$	180, 12 hrs.	. . . .; 121
$1,2,4,5\text{-}(CH_3)_3C_6H_2SO_3H$	C_6H_6	150, 4 hrs.	Small; 160
	$C_6H_5CH_3$	155, 3.5 hrs.	Small; 159
	$m\text{-}C_6H_4(CH_3)_2$	175, 3.5 hrs.	Small; 125
$1,3,5,6\text{-}(CH_3)_3C_6H_2SO_3H$	C_6H_6	160, 15 hrs.	Small; 116
	$C_6H_5CH_3$	160, 9 hrs.	20%; 119
	$m\text{-}C_6H_4(CH_3)_2$	160, 8 hrs.	Small; 149
$4\text{-}ClC_6H_4SO_3H$	C_6H_6	160, 20 hrs.	High; 91
	$C_6H_5CH_3$	160, 20 hrs.	High; 128
	C_6H_5Cl		. . . .; 146
$\beta\text{-}C_{10}H_7SO_3H$	$C_6H_5CH_3$	150, 12 hrs.	. . . .; 154
	$m\text{-}C_6H_4(CH_3)_2$	170, 10 hrs.	High; 128
	C_6H_5Cl	150, 10 hrs.	Very small; 136
$\beta\text{-}C_{10}H_{11}SO_3H$ (from tetralin)	$C_6H_5CH_3$	150, 12 hrs.	High; 112
	$m\text{-}C_6H_4(CH_3)_2$	165, ...	. . . .; 78
	$p\text{-}C_6H_4(CH_3)_2$	165, ...	. . . .; 115
	C_6H_5Cl	160.	. . . .; 136

In several instances the results were not in accord with those expected for a simple reaction. α-Naphthalenesulfonic acid with toluene forms naphthalene, *p*-toluenesulfonic acid, and *p*-tolyl sulfone. Benzene behaves analogously. 2,5-Dichlorobenzenesulfonic acid also loses the sulfo group when heated with toluene or *m*-xylene. 2-Chlorotoluene-5-sulfonic acid with toluene yields *p*-tolyl sulfone and with *m*-xylene xylyl *p*-tolyl sulfone. The sulfonic acid loses hydrogen chloride at 110° with formation of some *p*-toluenesulfonic acid so this pyrolysis probably precedes sulfone formation.

Decomposition of Alkyl and Arylsulfonylcarboxylic Acids. Carboxylic acids which have a sulfonyl group attached to the alpha carbon decompose readily with loss of carbon dioxide and formation of simple sulfones. Methylsulfonylacetic acid [34] yields methyl sulfone, and α-ethylsulfonylpropionic acid,[35] ethyl sulfone at 200°. Sulfonylbisacetic acid and sulfonyl-α,α-bispropionic acid [36] behave similarly.



$$\begin{array}{c} CH_3CHCOOH \\ | \\ SO_2 \\ | \\ CH_3CHCOOH \end{array} \xrightarrow{\Delta} (C_2H_5)_2SO_2 + 2CO_2$$

Heating either α-phenylsulfonylbutyric acid [37] or the sodium salt [38] gives phenyl *n*-propyl sulfone. α-Phenylsulfonylisobutyric acid [38] gives the isopropyl compound when heated at 170° with potassium hydroxide solution.

When bromosuccinic acid or α, β-dibromosuccinic acid is heated with sodium benzenesulfinate the carboxyl adjacent to a sulfone group is lost at once.[39] α-Phenylsulfonylphenylacetic acid [40] gives phenyl

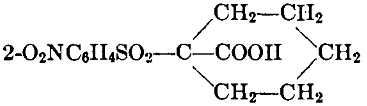
$$(CHBrCOOH)_2 + 2C_6H_5SO_2Na \rightarrow (CH_2SO_2C_6H_5)_2 + 2NaBr + 2CO_2$$

benzyl sulfone at 142°.

In a patent [41] there has been described the preparation of a large number of *o*-nitroaryl alkyl and aralkyl sulfones by decomposition of the alkali metal salts of α-(*o*-nitrophenylsulfonyl)-alkane-α-carboxylic acids by heating in a slightly basic aqueous solution. These nitro compounds were converted into the amines which were claimed to be of value as dye intermediates. The compounds prepared are listed in Table VIII.

Acids which have one or two halogen atoms attached to the α-carbon undergo loss of carbon dioxide at a much lower temperature than do the unsubstituted α-sulfonyl acids. When one halogen atom is present

TABLE VIII

Acid Decomposed	Nitroaryl Alkyl Sulfone, M.P., °C.	Aminoaryl Alkyl Sulfone, M.P., °C.
4,2-$Cl(O_2N)C_6H_3SO_2CH_2COOH$	155–156	87–88
4,2-$F_3C(O_2N)C_6H_3SO_2CH_2COOH$	150–151	94–95
4,2-$Cl(O_2N)C_6H_3SO_2CH(C_6H_5)COOH$	112–113	132–133
2-$O_2NC_6H_4SO_2CH_2COOH$	106–107	84–85
2-$O_2NC_6H_4SO_2CH(CH_3)COOH$	44–45	74–75
4,2-$Cl(O_2N)C_6H_3SO_2CH(C_2H_5)COOH$	73–74	54–55
2-$O_2NC_6H_4SO_2CH(C_6H_5)COOH$	127–128	156
	....	128–130
4,2-$Cl(O_2N)C_6H_3SO_2CH(CH_3)COOH$	123–125	87–89
4,2-$Cl(O_2N)C_6H_3SO_2CH(C_3H_7\text{-}n)COOH$	....	Oil, b.p. 225–226/8 mm.
5,2-$Cl(O_2N)C_6H_3SO_2CH_2COOH$	....	121–123
2,1-$O_2NC_{10}H_6SO_2CH_2COOH$	......	140–141
4,2-$CH_3(O_2N)C_6H_3SO_2CH_2COOH$	122–124	105–106
4,2-$CH_3(O_2N)C_6H_3SO_2CH(CH_3)COOH$	88–89	102
4,2-$CH_3(O_2N)C_6H_3SO_2CH(C_3H_7\text{-}n)COOH$	....	37–39
4,2-$CH_3(O_2N)C_6H_3SO_2CH(C_6H_5)COOH$	134–136	135–136
5,2-$CH_3O(O_2N)C_6H_3SO_2CH_2COOH$	....	100–102
4,2-$(O_2N)_2C_6H_3SO_2CH_2COOH$	....	199–200 (*o*-amino)
5-2-$(O_2N)_2C_6H_3SO_2CH_2COOH$	....	203–204 (*o*-amino)
4,2-$F_3C(O_2N)C_6H_3SO_2CH(CH_3)COOH$	116–118	42–43
4,2-$F_3C(O_2N)C_6H_3SO_2CH(C_6H_5)COOH$	134–135	193–195
4,2-$Cl(O_2N)C_6H_3SO_2CH(C_7H_7\text{-}p)COOH$	133–134	119–120
2-$O_2NC_6H_4SO_2CH(C_7H_7\text{-}p)COOH$	163–164	163
2-$O_2NC_6H_4SO_2CH(C_6H_3Cl_2\text{-}3,4)COOH$	148–149	150

decomposition of the free acid occurs in boiling water and the salts are too unstable to isolate. No sulfonyl dihaloacetic acid has ever been isolated because loss of the carboxyl group occurs spontaneously at room temperature. Several α-haloalkyl aryl sulfones have been obtained from the corresponding acids in good yields.[31,32,42] These are listed in Table IX.

The acids necessary to prepare the sulfones in Table IX have been synthesized by one of two methods which will be discussed later.

The preparation of dichloromethyl phenyl sulfone by the action of sodium hypochlorite upon phenyl cyanomethyl sulfone in alkaline solution[43] and of dibromomethyl phenyl sulfone by treating benzenesulfonyl-N-α-dibromoacetamide with 30% potassium hydroxide[44] probably involves the loss of the carboxyl group from the acids as

TABLE IX

SULFONE	M.P., °C.
$ClCH_2SO_2C_6H_5$	52–53
$ClCH_2SO_2C_6H_4CH_3$-*p*	84
$CH_3CHClSO_2C_6H_5$	52
$CH_3CHClSO_2C_6H_4CH_3$-*p*	84
$CH_3CHBrSO_2C_6H_5$	49–50
$C_2H_5CHBrSO_2C_6H_5$	77–78
$C_2H_5CHBrSO_2C_6H_4CH_3$-*p*	93–94
$Cl_2CHSO_2C_6H_5$	56
$Cl_2CHSO_2C_6H_4CH_3$-*p*	114
$Br_2CHSO_2C_6H_5$	76
$Br_2CHSO_2C_6H_4Cl$-*p*	115
$Br_2CHSO_2C_6H_4Br$-*p*	118
$Br_2CHSO_2C_6H_4CH_3$-*p*	116–117
$I_2CHSO_2C_6H_5$	96–97

intermediate steps. This obviously also occurs in the preparation of *p*-chlorophenyl and *p*-bromophenyl dibromomethyl sulfones by the

$$C_6H_5SO_2CH_2CN + NaOCl \rightarrow C_6H_5SO_2CCl_2CN \xrightarrow[H_2O]{NaOH} C_6H_5SO_2CHCl_2$$

$$C_6H_5SO_2CHBrCONHBr + KOH \rightarrow C_6H_5SO_2CBr_2CONH_2 \rightarrow C_6H_5SO_2CHBr_2$$

action of alcoholic alkali upon the dibromoacetates.[45]

$$p\text{-}ClC_6H_4SO_2CBr_2COOC_2H_5 + 2KOH \rightarrow p\text{-}ClC_6H_4SO_2CHBr_2 + C_2H_5OH + K_2CO_3$$

Bromination of β-hydroxyethylsulfonylacetic acid is of interest in that both loss of carbon dioxide and ether formation take place.[46]

$$2HOCH_2CH_2SO_2CH_2COOH + 4Br_2 \rightarrow 2CO_2 + (Br_2CHSO_2CH_2CH_2)_2O + 4HBr + H_2O$$

Carboxylic acids containing a sulfone group in the β-position do not lose carbon dioxide easily.[47] Potassium β-phenylsulfonylpropionate is unchanged by heating at 180°.

Miscellaneous Preparation Methods. A number of organometallic compounds yield sulfones when treated with esters or sulfonyl halides. Phenylmagnesium bromide[48] reacts with ethyl ethanesulfonate to give phenyl ethyl sulfone as one of the products, but the yield is small. On the other hand aryl *p*-toluenesulfonates give from 40 to 80% yields of sulfones with aryl Grignard reagents.[49] With alkylmagnesium halides the results are poorer. Diphenylcadmium and benzenesulfonyl chloride[50] give 15% of phenyl sulfone and a like amount of chlorobenzene, most of the sulfonyl chloride going to form the sulfinic acid. *p*-Toluenesulfonyl iodide and di-*p*-tolylmercury[51] were reported to react only partially but considering the material used in the reaction the yield of sulfone was practically quantitative. Benzenesulfonyl chloride[52] reacts at 160°.

$$(C_6H_5)_2Hg + 2C_6H_5SO_2Cl \rightarrow 2(C_6H_5)_2SO_2 + HgCl_2$$

It was found many years ago[53] by Frankland and Lawrance that sulfur dioxide and diethyllead react to give ethyl sulfone, but the reaction does not appear to have been studied further.

The pyrolysis of benzenesulfonic[54] acid yields a small amount of sulfone together with benzene and sulfuric and sulfurous acids. In the distillation of the crude mixture obtained in the preparation of phenylmethylcarbinyl sulfide a little of the sulfone was produced from an uncertain source.[55] The action of sulfuryl chloride upon benzene in the presence of aluminum chloride[56] produces a small yield of sulfone, chlorobenzene and benzenesulfonyl chloride being other products.

Phenylmethylcarbinyl *p*-toluenesulfinate rearranges[57] under a variety of conditions to give the sulfone. The best yield was obtained in formic acid solution.

Benzyl sulfone has been isolated as a by-product from the reaction of benzyl chloride with potassium sulfite.[58a] It is difficult to account for this, as the principal product, potassium ω-toluenesulfonate, would hardly be reduced to the sulfinate by potassium sulfite. In acid solution benzhydrol condenses with benzene- or α-naphthalenesulfinic acid[58b] to give the sulfone.

$$(C_6H_5)_2CHOH + C_6H_5SO_2H \rightarrow (C_6H_5)_2CHSO_2C_6H_5 + H_2O$$

p-Tolyl bromomethyl sulfone[59] has been prepared by treating the product obtained from *p*-tolyl methyl sulfone and ethylmagnesium bromide with bromine.

$$p\text{-}C_7H_7SO_2CH_2MgBr + Br_2 \rightarrow p\text{-}C_7H_7SO_2CH_2Br + MgBr_2$$

PROPERTIES AND REACTIONS OF SULFONES

Physical Properties. The melting and boiling points of a number of sulfones have been listed in the tables dealing with their preparation. The low-molecular-weight alkyl sulfones are water-soluble, high-boiling substances of great stability. Ethyl sulfone[60] dissolves in six times its weight of water at 16° while *n*-butyl sulfone[61] is reported to be insoluble. Phenyl sulfone[54] is slightly soluble in boiling water. *p*-Tolyl sulfone[62] distils undecomposed at 405° which is typical of the stability of the aryl sulfones.

The molecular refractions for a number of sulfones have been reported.[63] The absorption spectra for methyl sulfone,[64] bis-(β-chloroethyl) sulfone,[65] phenyl methyl sulfone, benzyl, and phenyl sulfones[66] have been determined. Phenyl sulfone exists in two allotropic forms,[67] m.p. 124° and 128°. The optical constants of the crystals[68] and also the heat capacity[69] from 100° to 320° K. have been measured. The originals should be consulted for the details of these investigations.

Effect of Reducing Agents. Neither the alkyl[70] nor aryl[71] sulfones are affected by zinc and dilute acid or by hydrogen iodide. Phenyl sulfone is also unaffected by heating to 250° with yellow phosphorus, and by distillation from zinc dust.[72] On the other hand, heating with sulfur gives a nearly quantitative yield of phenyl sulfide, a trace of phenyl disulfide, and sulfur dioxide.[73] The reaction of sulfur with substituted aryl sulfones is, however, not clean-cut.[73] The products obtained for a number of sulfones are shown below.

$$(p\text{-ClC}_6\text{H}_4)_2\text{SO}_2 + \text{S} \rightarrow \text{SO}_2 + p\text{-C}_6\text{H}_4\text{Cl}_2 + ?$$

$$p\text{-BrC}_6\text{H}_4\text{SO}_2\text{C}_6\text{H}_5 + \text{S} \rightarrow \text{SO}_2 + \text{C}_6\text{H}_5\text{Br} + \text{unchanged sulfone}$$

$$p\text{-ClC}_6\text{H}_4\text{SO}_2\text{C}_6\text{H}_4\text{Br-}p + \text{S} \rightarrow \text{SO}_2 + p\text{-ClC}_6\text{H}_4\text{Br} + p\text{-C}_6\text{H}_4\text{Br}_2 + ?$$

$$(p\text{-BrC}_6\text{H}_4)_2\text{SO}_2 + \text{S} \rightarrow \text{SO}_2 + p\text{-C}_6\text{H}_4\text{Br}_2$$

$$p\text{-CH}_3\text{C}_6\text{H}_4\text{SO}_2\text{C}_6\text{H}_4\text{Br}+\text{S} \xrightarrow{240°\text{-}250°} \text{H}_2\text{O}+\text{H}_2\text{S}+\text{HBr}+\text{“a red oil”}$$

$$p\text{-CH}_3\text{C}_6\text{H}_4\text{SO}_2\text{C}_6\text{H}_4\text{Br} + \text{S} \xrightarrow{340°} \text{SO}_2 + \text{HBr} + p\text{-C}_6\text{H}_4\text{Br}_2$$

$$(p\text{-BrC}_6\text{H}_4)_2\text{SO}_2 + \text{S} \xrightarrow{360°} \text{complete decomposition}$$

Heating phenyl sulfone with selenium produces phenyl selenide.[72] Metallic sodium in boiling xylene yields sodium benzenesulfinate and biphenyl.

$$2(\text{C}_6\text{H}_5)_2\text{SO}_2 + 2\text{Na} \rightarrow 2\text{C}_6\text{H}_5\text{SO}_2\text{Na} + \text{C}_6\text{H}_5\text{C}_6\text{H}_5$$

The yield of biphenyl was not high, however, considerable tarry material being formed.

Heating phenyl methyl sulfone with methylmagnesium iodide in boiling xylene brings about partial reduction to thiophenol.[74]

Treating bis-(α, β-dichloroethyl) sulfone with phosphorus pentachloride[75] produces first the dichloride, $(\text{ClCH}_2\text{CHCl})_2\text{SCl}_2$, which then loses hydrogen chloride to give a pentachlorosulfide. Passing hydrogen sulfide into an acetic acid solution of bis-(α,β-dichloroethyl) sulfone containing hydrogen bromide gives a good yield of the sulfide.[75] Although this procedure has apparently not been applied to unsubstituted sulfones there is no reason to believe that it will cause reduction. The presence of several chlorine atoms on adjacent carbons seems to activate the sulfone oxygens.

Distilling sodium β-naphthalenesulfonate with sodium cyanide[76] produces a little β-naphthyl sulfide as a by-product. It was suggested that this might arise from the reduction of the β-naphthyl sulfone present in the sodium β-naphthalenesulfonate. There seems to be no other evidence for this reaction.

Cleavage Reactions of Sulfones. The effect of sodium and of a Grignard reagent on sulfones was mentioned in the preceding section. A number of other reagents also bring about cleavage. Phenyl sulfone is converted to benzenesulfonic acid by warm sulfuric acid or oleum.[77] Dry chlorine reacts at 130° with formation of chlorobenzene and benzenesulfonyl chloride.[78] In the presence of iodine nuclear substitution occurs.[79] Phosphorus pentachloride[52] effects cleavage with formation of chlorobenzene and benzenesulfonyl chloride at 160–170°. However, ethyl sulfone was reported to be unattacked by either chlorine[80] or phosphorus pentachloride.[60,70b] *p*-Bromophenyl methyl sulfone[81] with the latter reagent at 200–210° is converted into methyl chloride, *p*-chlorobromobenzene, and thionyl chloride.

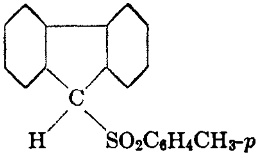
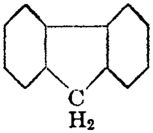
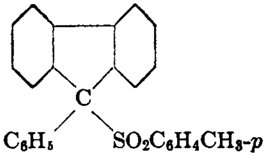
Phenyl methyl sulfone reacts with bromine at 250° giving methyl bromide, bromobenzene, and *p*-dibromobenzene.[82] In the presence of ferric chloride nuclear substitution occurs. Ethyl sulfone reacts with iodine trichloride at 150° in a complex manner[79,83] to give a mixture of chlorine derivatives of ethane and of the sulfone, together with some sulfuryl chloride.

Diethylzinc[60] has no effect on alkyl sulfones. This is also true for the Grignard reagent.

Hot 20% sodium hydroxide decomposes *p*-nitrobenzyl alkyl sulfones,[84] giving what is probably the dinitrostilbene. Other sulfones are unaffected by boiling dilute alkali. However, by heating with fused 90% potassium hydroxide at 200–235° the lower alkyl sulfones yield an olefin and the potassium sulfinate. Thus ethyl sulfone at 200° gives ethylene and potassium ethanesulfinate; ethyl *n*-octyl sulfone yields exclusively ethylene and potassium octane-1-sulfinate while *n*-octyl sulfone does not react.[85] *n*-Butyl sulfone decomposes very slowly but when one of the alkyls contains less than four carbons decomposition proceeds fairly readily.[86] Phenyl β-phenylethyl sulfone gives a 76% yield of benzene and 86% of styrene while phenyl sulfone is converted into phenol,[87] benzene, and biphenyl.[88] Traces of thiophenol and phenyl disulfide were also noted. The products from some other sulfones [87] are listed in Table IX.

TABLE IX

Sulfones and Potassium Hydroxide at 200°

Sulfone	Products
$(C_6H_5CH_2)_2SO_2$	$C_6H_5CH_3$, $C_6H_5CH{=}CHC_6H_5$, K_2SO_3
$C_6H_5CH_2SO_2CH_3$	$C_6H_5CH_3$, $C_6H_5CH{=}CHC_6H_5$, CH_3SO_2K, K_2SO_3
$C_6H_5CH_2SO_2C_6H_5$	$C_6H_5CH_3$, $C_6H_5CH{=}CHC_6H_5$ (48%), C_6H_6, C_6H_5OH, K_2SO_3
p-$CH_3C_6H_4SO_2CH_3$	$C_6H_5CH_3$ (25%), p-$CH_3C_6H_4OH$ (30%), p-$CH_3C_6H_4SO_2K$ (18%), CH_4 (13%), C_2H_4 (27%), H_2
	$C_6H_5CH_3$ (25%),  (45%), p-$CH_3C_6H_4OH$ (10%), $C_6H_5C_6H_4COOH$ (15%), $CH_3C_6H_4SO_2K$ (20%)
	$C_6H_5CH_3$, $(C_6H_4)_2CHC_6H_5$, p-$CH_3C_6H_4OH$, $(C_9H_{12})_4$, p-$CH_3C_6H_4SO_2H$

Sodium ethoxide was found to be a more satisfactory reagent,[89] than alkali for splitting various sulfones, even the higher alkyl compounds reacting. The procedure consisted of heating the sulfone with the sodium ethoxide containing a trace of alcohol to 200–235°. A number of *sym*-alkyl sulfones including *n*-octyl give the olefin and sulfinate. From phenyl β-phenylethyl sulfone were obtained 91% of styrene (isolated as dibromide) and 72% of benzenesulfinic acid (as silver salt). With potassium hydroxide the sulfinate was not isolated, benzene being produced by further reactions.

$$C_6H_5CH_2CH_2SO_2C_6H_5 + NaOC_2H_5 \rightarrow C_6H_5CH{=}CH_2 + C_6H_5SO_2Na + C_2H_5OH$$

The mechanism of these reactions is believed by Ingold to consist in the removal of a beta hydrogen by the alkali, followed by splitting of the carbon-sulfur bond, the hydrogen being "incipiently ionized" through the influence of the polar sulfone group.

Sodamide in piperidine has been found an excellent reagent for cleavage of most sulfones.[90] Phenyl sulfone gives N-phenylpiperidine and sodium benzenesulfinate. *p*-Tolyl methyl sulfone likewise cleaves to give the N-arylpiperidine, but benzyl sulfone does not behave normally.

Directive and Activating Influence of the Sulfone Group in the Benzene Ring. It was first reported[81] that bromination of methyl phenyl sulfone in the presence of ferric chloride gave *p*-bromophenyl methyl sulfone but this conclusion has been shown[91] to be erroneous, bromination, nitration, and sulfonation yielding almost entirely *meta* derivatives.

Styphnic acid (trinitroresorcinol) is a minor by-product from the nitration of phenyl methyl sulfone and also phenyl sulfone.[92] Its formation was promoted by the presence of sulfuric acid in the nitration mixture. In the nitration of several alkyl phenyl sulfones to obtain suitable derivatives for identification purposes,[93] heating at 100° with a mixture of concentrated sulfuric and nitric acids was a satisfactory procedure except for *t*-butyl and *t*-amyl phenyl sulfones which decomposed violently under these conditions. However, at 50° substitution occurred normally even with these compounds.

Nitration of a series of phenyl alkyl sulfones[94] was found to give a decreasing percentage of the *meta* isomer as the alkyl group increased in size. Analyses were made by reduction and quantitative bromination of the mixture of amines.

TABLE X

NITRATION OF ALKYL PHENYL SULFONES

Alkyl	Meta Isomer, %
CH_3	98
C_2H_5	96
n-C_3H_7	93
iso-C_3H_7	80
n-C_4H_9	86

Nitration of methyl benzyl sulfone[95] gives 42% *para*, 30% *meta*, and 28% *ortho* isomers. *m*-Nitrophenyl benzyl sulfone substitutes in a similar manner.[96] The one sulfone group on the side-chain carbon has about the same effect as two chlorines.

Nitration of phenyl sulfone yields the 3,3′-dinitro compound,[97] m.p. 197°. The dinitration of other aryl sulfones has been found to be a suitable means for their identification.[98] Substitution was assumed to occur in *meta* positions, one group in each ring.

As might be anticipated, nitration of bis-(4-chlorophenyl) sulfone gives first[99a] 4-chloro-3-nitrophenyl 4-chlorophenyl sulfone and then[99b] the bis-(4-chloro-3-nitrophenyl) sulfone. Nitration of 4-chlorophenyl 4-bromophenyl sulfone[100] gives 34% of the 3-nitro-4-chloro and 66% of the 3-nitro-4-bromo compound.

Phenyl *p*-tolyl sulfone[101a] has been dinitrated and trinitrated; in the latter reaction two nitro groups are introduced ortho to the methyl. Mesityl sulfone[101b] has been dinitrated, one group entering each benzene nucleus.

The action of chlorosulfonic acid upon phenyl methyl,[91] phenyl ethyl,[102] and *p*-chlorophenyl ethyl sulfone[103a] gives the corresponding *m*-sulfonyl chloride. The structure was satisfactorily established for the methyl compound. Phenyl 3-chloro-4-nitrophenyl sulfone has been converted into a sulfonic acid[103b] by the action of oleum.

Because of the strongly *meta*-directing influence of the sulfone group it would be expected to activate a halogen atom located *ortho* or *para* to it in the benzene ring. The effect is not as great, however, as that of the nitro group[104] when alcoholic sodium ethoxide is the halogen-removing agent. Data are given in Table XI.

TABLE XI

ACTIVATING INFLUENCES OF NITRO AND SULFONE GROUPS

Compound	% Cl Removed 1 hr.	% Cl Removed 4 hrs.
o-$ClC_6H_4NO_2$	24.7	36.5
o-$ClC_6H_4SO_2CH_3$	1.76	5.33
m-$ClC_6H_4NO_2$	0.49	.....
m-$ClC_6H_4SO_2CH_3$	0.06	.....
p-$ClC_6H_4NO_2$	26.2	41.7
p-$ClC_6H_4SO_2CH_3$	1.34	3.8

Loudon and co-workers[105] have investigated the reactions of aromatic halogen when both nitro and sulfone groups are attached to the benzene ring. In compounds with the formula 2,4-$Cl(NO_2)C_6H_3SO_2Ar$ the nature of the Ar had little effect upon the reactions. In general, the mobility of the halogen was largely determined by the nitro group although the sulfone linkage had some influence. These results are in accord with the results shown in Table XI.

The activity of the bromine in some *p*-bromophenyl alkyl sulfones[106] toward hydrazine in absolute alcohol at 120° (sealed tube) or less has been utilized in the preparation of a series of *p*-alkylsulfonylphenylhydrazines. The compounds prepared in this manner are listed in Table XII.

The only compounds which did not react with hydrazine were the disulfones, 1,2-di-(*p*-bromophenylsulfonyl)-ethane and 1,5-di-(*p*-bromophenylsulfonyl)-pentane.

TABLE XII

RSO_2- of p-$RSO_2C_6H_4NHNH_2$	M.P. of Sulfone, °C.
CH_3SO_2-	135–136
$C_2H_5SO_2$-	112–113
n-$C_3H_7SO_2$-	104–105
iso-$C_3H_7SO_2$-	110–111
n-$C_4H_9SO_2$-	139–140
iso-$C_4H_9SO_2$-	127–128
iso-$C_5H_{11}SO_2$-	143
n-C_6H_{13}-SO_2-	125–126
$C_6H_5CH_2SO_2$-	?
$C_6H_5(CH_2)_2SO_2$-	144–145
$C_6H_5SO_2$-	202–203

Extensive use has been made of the reaction between halogenated aryl sulfones and ammonia and amines in making amino sulfones. These reactions are described in the section on "Amino Sulfones."

It was found by Holt and Reid[107] that p-bromophenyl methyl sulfone gave no reaction toward magnesium. Apparently no Grignard reagent containing a sulfone group has been prepared.

A number of nitroaryl sulfones containing one or more methyls *ortho* or *para* to the nitro groups condense readily with aldehydes and with p-nitrosodimethylaniline[101a] in the presence of a trace of piperidine. Although the sulfone group seems to facilitate this condensation, the reaction does not proceed in the absence of a nitro group, even if two sulfone groups are attached to the aromatic nucleus.

$$4,3\text{-}CH_3(NO_2)C_6H_3SO_2C_6H_5 + C_6H_5CHO \rightarrow 4,3\text{-}C_6H_5CH{=}CH(NO_2)C_6H_3SO_2C_6H_5 + H_2O$$

Activation of Adjacent Methylene Hydrogens by the Sulfone Group. Most of the investigations on the activating influence of a sulfone group on the hydrogens attached to an adjacent carbon have dealt with keto sulfones, alkyl or arylsulfonyl acids, and their derivatives, or disulfones, which are all discussed in later sections. The behavior of aryl benzyl sulfones and benzyl sulfones is outlined here.

Phenyl benzyl sulfone is slightly soluble in dilute alkali whereas benzyl sulfone does not dissolve at all.[108a] Sodium metal liberates hydrogen very slowly, ferric chloride gives no appreciable color, and attempts at alkylation with sodium ethoxide in alcohol give negative results. p-Tolyl benzyl sulfone[108c] does not give the mercuric chloride test for enolic substances, does not condense with benzaldehyde or isoamyl nitrite, and is not oxidized by selenium dioxide. However, the Michael condensation with benzalacetophenone does take place to give two stereoisomeric products.

$$p\text{-}C_7H_7SO_2CH_2C_6H_5 + C_6H_5CH{=}CHCOC_6H_5 \rightarrow p\text{-}C_7H_7SO_2CH(C_6H_5)CH(C_6H_5)CH_2COC_6H_5$$

It was reported earlier[108b] that benzyl sulfone condenses with formaldehyde in the presence of sodium hydroxide to give an inert compound of unknown structure.

$$(C_6H_5CH_2)_2SO_2 + 2HCHO \rightarrow C_{16}H_{16}SO_3 + H_2O$$

It is stable toward a boiling hydrochloric acid-acetic acid mixture and toward potassium permanganate. It does not react with an acyl halide. It is unchanged by boiling with nitric acid or fusion with sodium hydroxide. Reduction with hydrogen iodide and phosphorus at 160° gives a mixture of hydrocarbons. Bromine has no reaction in chloroform but with pure bromine a mixture of bromo compounds results. One of these has the composition $C_{16}H_{14}SO_3Br_2$. It was found upon further investigation that *p*-tolyl benzyl sulfone likewise condenses with formaldehyde to give an unreactive product. Phenyl benzyl sulfone is less reactive.

The introduction of nitro groups into the benzyl part of the molecule enhances the activity of the methylene hydrogens to some extent.[109] The *o*- and *p*-nitrobenzyl *p*-tolyl sulfones give colored salts with sodium ethoxide in alcohol and these react readily with bromine. The *m*-nitrobenzyl compound does not brominate under these conditions.

$$p\text{-}C_7H_7SO_2CHNaC_6H_4NO_2+Br_2 \rightarrow p\text{-}C_7H_7SO_2CHBrC_6H_4NO_2+NaBr$$

The report[110] that *p*-nitrophenyl benzyl sulfone can be alkylated with methyl iodide and alcoholic alkali to a dimethyl derivative has not been verified.[109, 111] 2,4-Dinitrobenzyl *p*-tolyl sulfone is much more acidic than the other benzyl compounds.[108] The potassium salt was isolated and alkylation with methyl iodide occurred readily.

Reactions of α-Haloalkyl Sulfones. A halogen atom in the alpha position to a sulfone group shows a number of interesting properties. In general, double decomposition reactions occur with difficulty while replacement of the halogen by hydrogen takes place more readily than it does for alkyl halides.

It has already been mentioned (see p. 667) that halomethyl aryl sulfones are reduced by sodium benzenesulfinate to the methyl phenyl sulfone. Removal of the halogen is more readily effected by zinc and sulfuric acid[112] in alcohol. Sodium amalgam converts chloromethyl phenyl sulfone to sodium benzenesulfinate and an unidentified gas. Sodium in an anhydrous solvent has no effect. Bromomethyl sulfones,[59] $BrCH_2SO_2R$, and iodomethyl phenyl sulfone[112] are reduced to the methyl sulfones by heating with sodium ethoxide but α-bromoethyl and α-chloroethyl phenyl sulfones are more inert toward this reagent. Refluxing dichloromethyl phenyl sulfone with alcoholic sodium ethoxide for eight days gives chloromethyl phenyl sulfone and sodium benzenesulfonate.[113]

Bromomethyl sulfones[59] are also reduced to the methyl compounds by phenylmagnesium bromide, and by *p*-thiocresol and 1-butanethiol in alkaline solution but not by hydrazine or hydriodic acid. Curiously enough, pyridine effects a sort of Wurtz reaction although the yield of disulfone obtained was small. Tetrahydroquinoline and dimethylamine brought about no change.

$$2RSO_2CH_2Br \rightarrow (RSO_2CH_2)_2 \; [+ 2Br]$$

Heating chloromethyl phenyl sulfone[112] with silver oxide in alcohol to 140° has no effect and the bromomethyl alkyl and aryl sulfones[59] are unaffected by alcoholic silver nitrate, sodium acetate, or sodium cyanide. This behavior is similar to but more extreme than that of α-haloalkyl ketones.

Warming dibromomethyl phenyl sulfone with excess bromine and alkali gives tribromomethyl phenyl sulfone[114a] but no bromoform, the similarity in the effects of keto and sulfone groups not extending to this reaction.

α-Bromoethyl ethyl sulfone[114b] behaves the same as the bromomethyl sulfones toward silver nitrate, hydrazine, and iodide ion. By heating with 2 *N* potassium hydroxide at 90–100° it is converted rapidly into *cis*-2-butene in 85% yield.

$$CH_3CHBrSO_2C_2H_5 + 3KOH \rightarrow C_4H_8 + K_2SO_3 + KBr + 2H_2O$$

β-Haloalkyl Sulfones. Unlike an α-halogen atom, one in the β-position to a sulfone group reacts but little differently than one in an alkyl halide. Bis-(β-chloroethyl) sulfone is somewhat less active toward potassium phthalimide and similar reagents than are the corresponding sulfide and sulfoxide.[115] Alkali converts it into the cyclic ether and alcoholic sodium hydroxide gives the diethoxy compound.[116] β-Bromoethyl ethyl sulfone[115] and silver nitrate solution gradually give silver bromide. The reaction is much faster in slightly alkaline solution than in the presence of nitric acid. The reaction with 0.25 *N* potassium hydroxide is rapid even at room temperature giving vinyl ethyl sulfone. The preparation of vinyl sulfones is described in more detail in the section on unsaturated sulfones.

β-Chloroethyl phenyl sulfone is unchanged by heating to 150° with water in a sealed tube and is not reduced by zinc and hydrochloric acid but silver oxide in benzene converts it to the ether, sodium benzenesulfinate gives the disulfone, and ammonia and sodium hydrosulfide react normally.[117]

$$2C_6H_5SO_2CH_2CH_2Cl + 2NH_3 \rightarrow (C_6H_5SO_2CH_2CH_2)_2NH_2Cl + NH_4Cl$$

$$2C_6H_5SO_2CH_2CH_2Cl + 2KSH \rightarrow (C_6H_5SO_2CH_2CH_2)_2S + H_2S + 2KCl$$

The effect of substituents in the benzene ring upon the rate at which aryl β-chloroethyl sulfones react with an iodide has been studied quantitatively.[118]

Various β-halopropyl and β,γ-dihalopropyl aryl sulfones have been obtained from allyl sulfones (see p. 728) but the chemical properties of these compounds have not been studied except to note that they can be hydrolyzed to the corresponding alcohols.[119]

$$C_6H_5SO_2CH_2CHBrCH_2Br + 2H_2O \xrightarrow{110^\circ} C_6H_5SO_2CH_2CHOHCH_2OH + 2HBr$$

With alcoholic potassium hydroxide, however, the reaction takes a different course,[119] yielding ethynylcarbinol and potassium benzenesulfinate.

$$C_6H_5SO_2CH_2CHBrCH_2Br \rightarrow C_6H_5SO_2CH_2C{\equiv}CH \rightarrow C_6H_5SO_2Na + HC{\equiv}CCH_2OH$$

Because of the intense interest in the properties responsible for the toxic action of bis-(β-choloroethyl) sulfide the corresponding sulfone and other compounds with the general formula $ClCH_2CH_2SO_2R$ have been much investigated with regard to their physiological effects. A 2% aqueous solution of bis-(β-chloroethyl) sulfone is non-toxic cutaneously[120] but is toxic when injected intracutaneously in water or alcohol solution. It was considered possible that the effect of the sulfide may result from its oxidation to the sulfone. The hemolysis of red blood cells by bis-(β-chloroethyl) sulfone is apparently caused by liberation of hydrogen chloride, at least in vitro[121] as it is reduced by the addition of a buffer. For the results of other investigations[122] the original reports should be consulted.

Miscellaneous Properties and Reactions of Sulfones. Hinsberg[123] has reported some exceptionally interesting investigations dealing with the preparation of sulfides and sulfones that are isomeric with the compounds hitherto known. Thus 70% perchloric acid reacts with phenyl sulfide to give a perchlorate believed to have the formula $C_6H_5S(OClO_3){=}C(CH{=}CH)_2CH_2$. The sulfide from this with hydrogen peroxide yields a sulfone, $(C_6H_5)_2SO_2 \cdot 0.5H_2O$, which melts at 81° and is referred to as β-phenyl sulfone. Basic β-diphenylsulfonium perchlorate is oxidized to a compound $C_{24}H_{27}O_9ClS_2$ which with potassium hydroxide gives both the normal phenyl sulfide and the β-phenyl sulfone. The β-sulfide gives a blue color with sulfuric acid similar to that shown by thianthrene. Heating the β-phenyl sulfone with perchloric acid (70%) converts it into $C_{12}H_{10}O_3S \cdot H_2O$ which Hinsberg believes is a trioxide of the sulfide. It is not reduced by zinc and hydrochloric acid. *n*-Butyl sulfide and benzyl sulfide likewise undergo little-understood changes with perchloric acid, the resulting sulfides and sulfones having uncertain structures.

The oxidation of the sulfone obtained from *m*-diphenylbenzene and benzenesulfonyl chloride[124] gives *p*-phenylsulfonylbenzoic acid, indicating that the rings attached to the sulfone group are more stable than the others.

The analytical determination of sulfur in sulfones by oxidation in a stream of oxygen in the presence of sodium carbonate is facilitated by cobalt oxide.[125] The sulfur was determined as barium sulfate as usual.

Several sulfones have been suggested as useful for various purposes. Bis-(2,4,6-trinitrophenyl) sulfone[126] has been suggested for use as an explosive. It passed the stability tests satisfactorily. β-Alkylsulfonylethanesulfonates,[127] $RSO_2CH_2CH_2SO_3Na$, have been suggested for use as detergents and wetting agents.

As might be expected from their chemical inertness sulfones do not exert a catalytic effect in the oxidation of furfural by oxygen.[128] Butyl sulfone gives a negative result on the copper strip in corrosion tests of gasoline.[129] The fate of sulfones in a naphtha solution when treated with various refining agents has been studied.[130]

HYDROXY SULFONES

α-Hydroxyalkyl Aryl Sulfones. *p*-Toluenesulfinic acid has been observed to form unstable addition products with both aliphatic and aromatic aldehydes.[131]

$$CH_3C_6H_4SO_2H + HCHO \rightarrow CH_3C_6H_4SO_2CH_2OH$$

These are analogous to bisulfite addition products of aldehydes, and are probably hydroxysulfones. Ketones do not form addition compounds of this type. The hydroxysulfones which have been characterized are listed below. The derivatives from aromatic aldehydes are more stable than the others. Cinnamic aldehyde adds *p*-toluenesulfinic acid first at the double bond, finally giving a disulfone which, however, was too unstable to be obtained in an entirely pure condition.

TABLE XIII

α-Hydroxysulfone	M.P., °C.
p-$CH_3C_6H_4SO_2CH_2OH$	90
p-$CH_3C_6H_4SO_2CHOHCH_3$	52–72 (decomp.)
p-$CH_3C_6H_4SO_2CHOHCH(CH_3)_2$	Decomp. in air
p-$CH_3C_6H_4SO_2CHOH(CH_2)_5CH_3$	Decomp. in air
p-$CH_3C_6H_4SO_2CHOHC_6H_4NO_2$-*m*	110
p-$CH_3C_6H_4SO_2CHOHC_6H_4NO_2$-*p*	116

$$C_6H_5CH{=}CHCHO + 2CH_3C_6H_4SO_2H \rightarrow C_6H_5CH(SO_2C_6H_4CH_3)CH_2CHOHSO_2C_6H_4CH_3$$

Hydroxymethyl *p*-tolyl sulfone is decomposed by heat or alkali to give formaldehyde and the sulfinate. Ammonia and aniline react to replace the hydroxyl group. The hydroxy-sulfones derived from aromatic aldehydes are decomposed by these reagents. Acetic anhydride acetylates hydroxymethyl *p*-tolyl sulfone while α-hydroxy-*m*-nitrobenzyl *p*-tolyl sulfone is cleaved to give *m*-nitrobenzaldehyde diacetate.

$$p\text{-}CH_3C_6H_4SO_2CH_2OH + C_6H_5NH_2 \rightarrow p\text{-}CH_3C_6H_4SO_2CH_2NHC_6H_5 + H_2O$$

β- and γ-Hydroxyalkyl Aryl Sulfones. β-Hydroxyethyl phenyl sulfone and several analogs have been prepared by hydrolysis of γ-disulfones with dilute alkali. The ether of the alcohol results as a by-product in this reaction, the amount formed increasing with an increase in the concentration of the alkali.[132] α,β-Diphenylsulfonylpropane hydrolyzes at the primary carbon.[133] This is somewhat surprising in view of the finding that a secondary alkyl sulfone hydrolyzes more readily than a primary one.[134]

$$C_6H_5SO_2CH_2CH(SO_2C_6H_5)CH_3 + NaOH \rightarrow C_6H_5SO_2Na + CH_2OHCH(SO_2C_6H_5)CH_3$$

In Table XIV are listed the alcohols obtained from γ-disulfones.

An alternative method of synthesis is by the action of ethylene chlorohydrin upon a sulfinate.[135] 2-Nitrophenyl β-hydroxyethyl sul-

TABLE XIV

Sulfone	M.P., °C.
$C_6H_5SO_2CH_2CH_2OH$	Syrup
o-$CH_3C_6H_4SO_2CH_2CH_2OH$	Syrup
p-$CH_3C_6H_4SO_2CH_2CH_2OH$	54–55
o-$CH_3OC_6H_4SO_2CH_2CH_2OH$	82
p-$ClC_6H_4SO_2CH_2CH_2OH$	Oil (impure)
p-$BrC_6H_4SO_2CH_2CH_2OH$	50–52
m-$O_2NC_6H_4SO_2CH_2CH_2OH$	78.5
2,5-$(CH_3)_2C_6H_3SO_2CH_2CH_2OH$	Oil
$C_6H_5SO_2CH(CH_3)CH_2OH$	46
α-$C_{10}H_7SO_2CH_2CH_2OH$	Colorless oil
β-$C_{10}H_7SO_2CH_2CH_2OH$	88–90

fone has been prepared by oxidation of the sulfoxide acetate with hydrogen peroxide followed by hydrolysis.[136] A similar procedure has been applied to the synthesis of 1-anthraquinonyl β-hydroxyethyl sulfone.[137] The benzoate of β-hydroxyethyl benzyl sulfide[138] is oxidized to the sulfone by permanganate. This with sodium ethoxide yields the ether which can in turn be hydrolyzed.

$$2\text{-}NO_2C_6H_4SOCH_2CH_2OOCCH_3 \xrightarrow{H_2O_2}$$

$$2\text{-}NO_2C_6H_4SO_2CH_2CH_2OOCCH_3 \xrightarrow{NaOH} 2\text{-}NO_2C_6H_4SO_2CH_2CH_2OH$$

$$C_6H_5COOCH_2CH_2SO_2CH_2C_6H_5 \xrightarrow{C_2H_5ONa}$$

$$C_2H_5OCH_2CH_2SO_2CH_2C_6H_5 \xrightarrow{NaOH} HOCH_2CH_2SO_2CH_2C_6H_5$$

Bis-(tetraacetylglucosyl)-1,1-sulfone, the corresponding galactosyl derivative, and also a 6,6-sulfone derived from glucose have been prepared by oxidation of the corresponding sulfides with permanganate in acetic acid.[139] It is not necessary that the hydroxyl group or groups be acylated during oxidation with hydrogen peroxide as 2-carboxyphenyl β-hydroxyethyl sulfone and dodecyl β-hydroxyethyl sulfone[140] are readily prepared from the sulfides in acetic acid solution.

β-Hydroxyethyl phenyl sulfone is only slightly soluble in water but is much more so in dilute alkali. This suggests acid properties which are not accounted for by the structure, and further investigation is needed to explain this behavior. Zinc and alcoholic hydrogen chloride have no effect but sodium amalgam gives ethyl alcohol and benzenesulfinic acid. By the action of phosphorus trichloride, phosphorus pentoxide, or hot sulfuric acid, the ether is formed[141] whereas with phosphorus pentachloride or hydrochloric acid at 150° the chloride is produced. The phosphorus pentachloride reaction has been utilized in converting a number of hydroxyethyl aryl sulfones into their chlorides.[135b] Hydriodic acid at 160° gives the corresponding iodide and at ordinary temperatures sulfuric acid gives the acid sulfate. Esters of the general formula $RSO_2CH_2CH_2OSO_3Na$ where R is an alkyl group having more than six carbon atoms are claimed[142] to have emulsifying and soaplike qualities. Strong aqueous ammonia at 120° in a sealed tube with phenyl β-hydroxyethyl sulfone yields the secondary amine. Phenylsulfonylacetic acid has been obtained

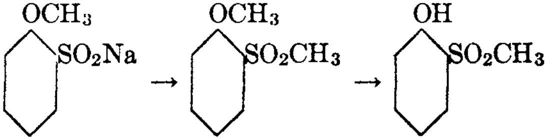
$$2C_6H_5SO_2CH_2CH_2OH + NH_3 \rightarrow (C_6H_5SO_2CH_2CH_2)_2NH + 2H_2O$$

by oxidation.[143]

$$C_6H_5SO_2CH_2CH_2OH \xrightarrow{[O]} C_6H_5SO_2CH_2COOH + H_2O$$

γ-Hydroxyalkyl sulfones have been little studied. γ-Ethoxypropyl benzyl sulfone[144] has been prepared by oxidation of the sulfide.

Hydroxyaryl Alkyl Sulfones. In the only satisfactory method so far described for the preparation of hydroxyaryl alkyl sulfones a methoxybenzenesulfinic acid is alkylated to the sulfone[145] and this is demethylated by heating with hydrobromic acid.[146]



The *o*-hydroxyphenyl methyl sulfone described by Holt and Reid[147] as melting above 220° was obtained from the corresponding amine by diazotization and hydrolysis. Although it gave a correct analysis for sulfur crystallization was not possible. The *o*-hydroxyphenyl methyl sulfone prepared by demethylation was isolated as the hydrate, m.p. 87.5°, and the anhydrous form melted even lower.[146] Several other hydroxyaryl methyl sulfones were isolated as hydrates but these were not limited to the *ortho* isomers. Data on the boiling points and solubilities for the isomeric hydroxysulfones would be of interest because of the possible effect on these properties of having hydroxyl and methylsulfonyl groups in positions allowing hydrogen bond formation.

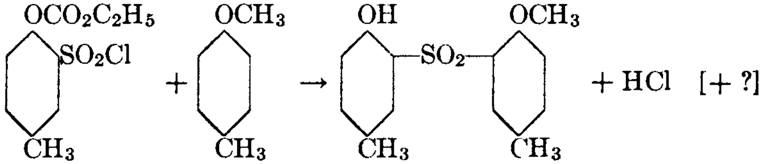
In the naphthalene series a 2-hydroxynaphthyl methyl sulfone has been prepared from the sulfide by oxidation and also by methylation of sodium 2-naphthol-6-sulfinate.[148] Various derivatives of this sulfone were also prepared.

Hydroxyaryl Sulfones and Their Ethers. Hydroxyphenyl aryl sulfones may be obtained by heating aluminum chloride with phenol at temperatures below 100° and then heating the product with a sulfonyl chloride[149] at 130°.

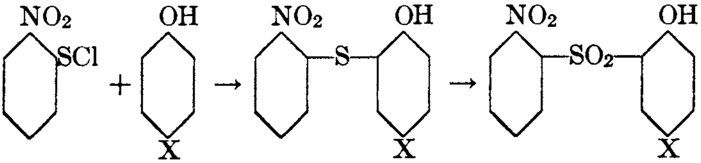
$$C_6H_5OH \xrightarrow{AlCl_3} C_6H_5OAlCl_2 \xrightarrow{p\text{-}C_7H_7SO_2Cl} o\text{-}HOC_6H_4SO_2C_7H_7\text{-}p$$

An alternative procedure, analogous to the Fries reaction, is to heat an aryl sulfonate with aluminum chloride to 150° either in the absence of a solvent, in nitrobenzene,[150] or in carbon disulfide solution[151] at the boiling point. Heating p-tolyl benzenesulfonate with hydrogen fluoride[151] also brings about rearrangement although the yield of hydroxy sulfone is only 10%.

An unusual application of the Friedel-Crafts method is the reaction of carbethoxy-p-cresolsulfonyl chloride with methyl p-tolyl ether.[146] The carbethoxy group is lost during the reaction, but the methoxyl remains intact. A number of methoxyaryl phenyl sulfones have been made by condensing the sulfonyl chlorides with benzene.[146] Demethylation with hydrobromic acid gives the hydroxy compounds.

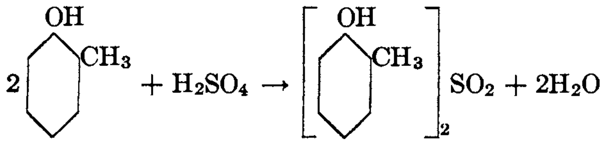


Numerous o-hydroxyaryl sulfones have been prepared by condensing an arylsulfur chloride with a *para*-substituted phenol[152] and oxidizing the sulfide with hydrogen peroxide. It is of interest that the sulfur can be oxidized without destroying the phenol nucleus.



Passing toluene vapor through p-phenolsulfonic acid at 150–160° for 20 hours gives a mixture of the two *sym*-aryl sulfones rather than p-hydroxyphenyl p-tolyl sulfone.[38]

Heating a phenol with a limited amount of sulfuric acid or oleum at a high temperature gives fair yields of the *sym*-sulfones. Thus heating o-cresol[153a] with one-half its weight of 8% oleum at 160–180° for 3 to 4 hours gives a 66% yield of the *para* sulfone. An equivalent



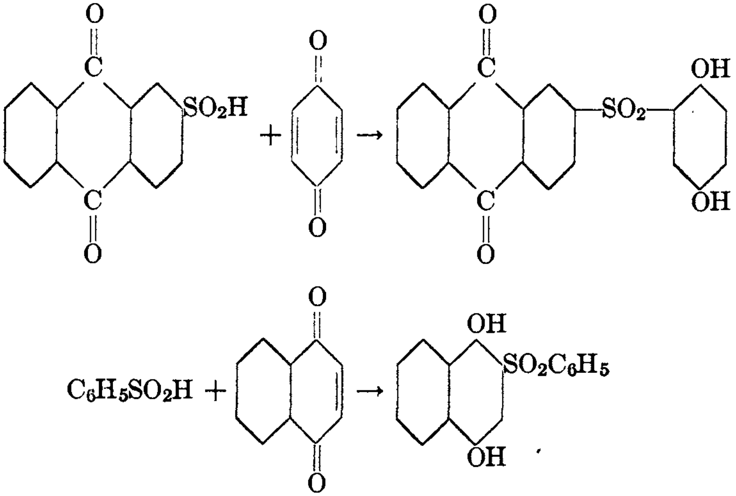
procedure is to heat a phenol with a phenolsulfonic acid.[153b] Another

$$C_6H_5OH + HOC_6H_4SO_3H \rightarrow (HOC_6H_4)_2SO_2 + H_2O$$

patent[153c] claims sulfone formation occurs when a crude sulfonation mixture is heated with phenol. *p*-Cresol[154] gives less than 10% of the sulfone when heated with oleum.[153a] Sulfones have also been prepared from *m*-cresol,[155] *p*-xylenol,[156] 2,4-dimethylphenol,[157] and 3,4-dimethylphenol.[157]

By heating a mixture of two phenols with sulfuric acid a mixture of sulfones results which includes the unsymmetrical compound. This procedure has been used with phenol-*p*-cresol[158] and phenol-*o*-cresol mixtures.[159] 3-Methoxy-2-naphthyl 2,4-dinitrophenyl sulfone[160] has been prepared from the methoxynaphthalenesulfinic acid and 2,4-dinitrochlorobenzene.

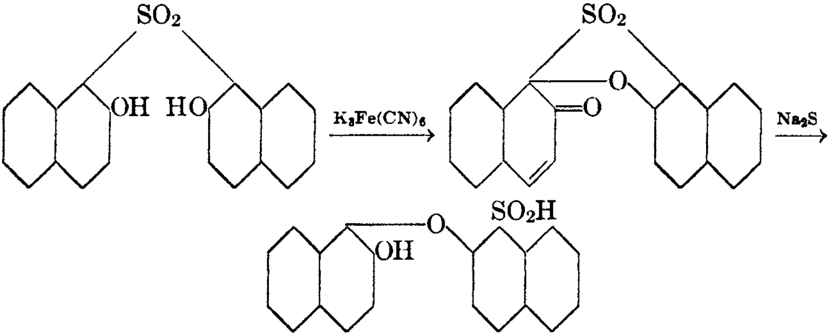
The condensation of a sulfinic acid with a quinone yields the dihydroxyaryl sulfone.[161]



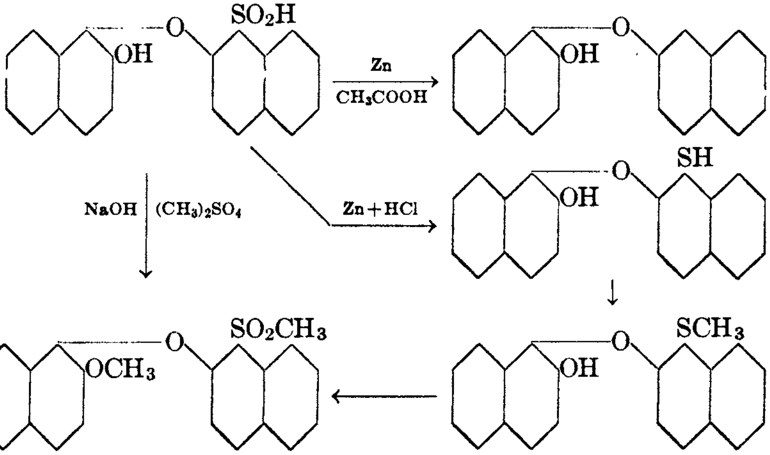
The reaction also occurs between *o*-naphthoquinone and *β*-naphthalenesulfinic acid so may be regarded as general. The formation of 2,5-dihydroxyphenyl *p*-tolyl sulfone from *p*-toluenesulfonhydrazide and quinone[162] probably involves a preliminary conversion of the sulfonhydrazide to the sulfinic acid.

The sodium salt of *o*-hydroxyphenyl phenyl sulfone[146] is soluble in cold chloroform and melts at 290–293°. Apparently it is non-ionic in structure. The free hydroxy compound forms a hydrate.

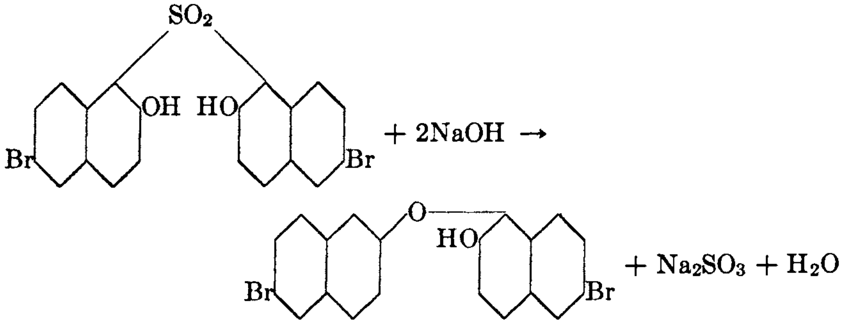
Certain *o*-hydroxyaryl sulfones undergo reactions involving both the hydroxyl and sulfone groups. It was first noted by Hinsberg[163] that oxidation of bis-1-(2-hydroxynaphthyl) sulfone with potassium ferricyanide produces a dehydrosulfone. Upon reduction with sodium sulfide this gives a compound isomeric with the original sulfone. This "isosulfone" of Hinsberg was subsequently shown by Warren and Smiles[164] to be a sulfinic acid, its formation being explained as follows.



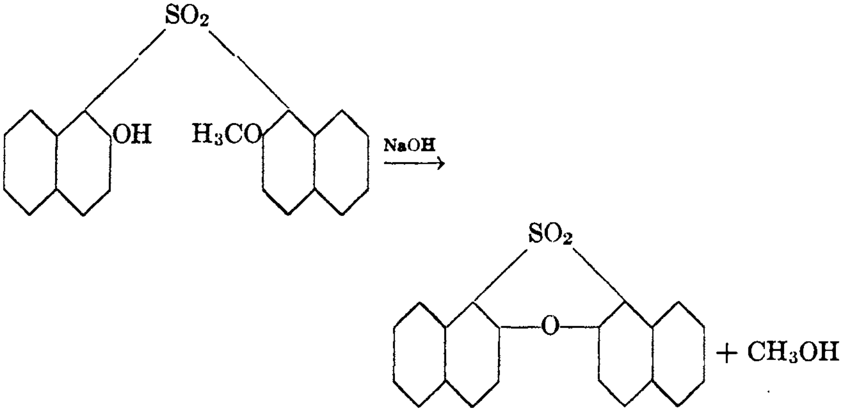
The reactions offered in proof of the structure of the sulfinic acid are formulated below.



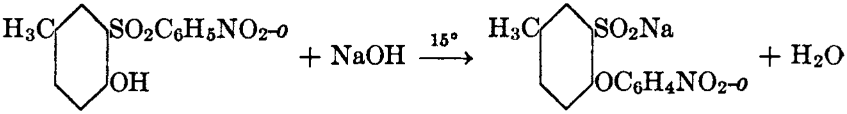
Later[152f] it was found that alkali at 150° converts the naphthyl sulfone into the sulfinic acid without going through the intermediate dehydrosulfone. Under these conditions the sulfinic acid cannot be isolated, however, as it loses sulfur dioxide in hot alkali. Bis-1-(2-hydroxy-6-bromonaphthyl) sulfone reacts analogously.



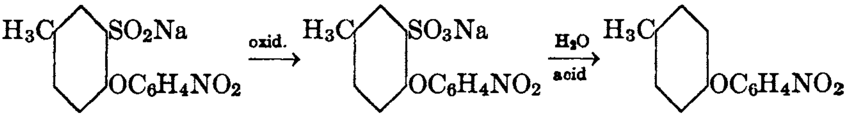
If one of the hydroxyl groups is methylated alkali brings about ring closure to a naphthoxthin.



These results led to an investigation of the behavior of a variety of hydroxy sulfones toward alkali. It was discovered that bis-(4-methyl-2-hydroxyphenyl) sulfone does not rearrange even when heated to 250° with alkali but when a nitro group is *ortho* to the sulfone linkage in one ring reaction occurs readily even at room temperature.[152d] The structure of the resulting sulfinic acid was determined



by the reactions formulated below. The 4-tolyl 2-nitrophenyl ether



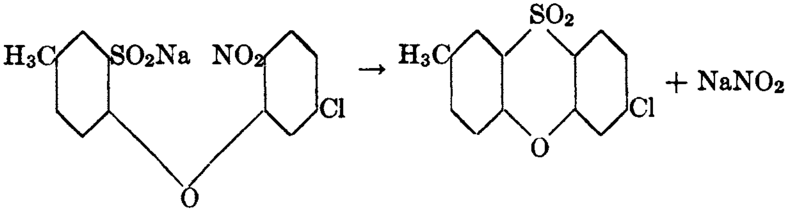
was synthesized from *o*-chloronitrobenzene and *p*-cresol.

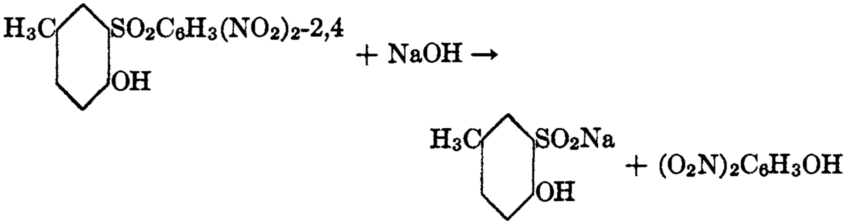
Rearrangements similar to the foregoing occur with a variety of compounds, including 2-nitrophenyl 2-hydroxy-1-naphthyl sulfone, 4-nitrophenyl 5-methyl-2-hydroxyphenyl sulfone,[152g] *p*-methylsulfonylphenyl 2-hydroxy-1-naphthyl sulfone,[152e] and 2-hydroxy-5-methylphenyl 1-anthraquinonyl sulfone.[152c] The relative rates of rearrangement at 50° for a series of nitroaryl sulfones [152b] are shown in Table XV. The reactions were carried out in 0.066 *N* sodium hydroxide, 1.25 moles of alkali being used to each mole of sulfone. The reaction rate was determined by the color change occurring in the solutions. With the nitro group in the *meta* position no reaction occurs. An *ortho* carboxy group also is without effect. With a chlorine *para* to the nitro group a phenoxthin derivative is the final product. With nitro groups both *ortho* and *para*, rapid hydrolysis ensues. If the hydroxyl is *para* instead of *ortho* to the sulfone group hydrolysis likewise is the main reaction.[152g] With the hydroxyl in an aliphatic side chain, rearrangement occurs very rapidly. Finally, the sulfone and

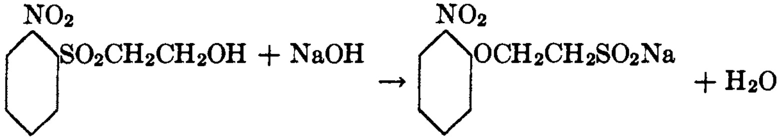
TABLE XV

REARRANGEMENT OF SULFONES AT 50°

Aryl Group of *o*-Nitrophenyl Aryl Sulfone	Rearrangement Time, Minutes
2-Hydroxy-5-methylphenyl	315
2-Hydroxy-3,5-dimethylphenyl	93
2-Hydroxy-1-naphthyl	5
2,5-Dihydroxyphenyl	125
2-Hydroxy-5-methoxyphenyl	360
2,4-Dihydroxyphenyl	420





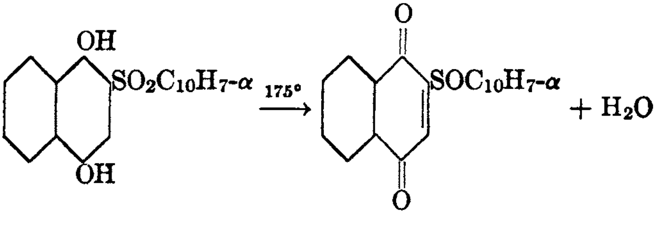


hydroxyl groups may be in different molecules showing that the rearrangements are actually special cases of a general reaction characteristic of *o*-nitroaryl sulfones. It may be predicted that *o*-nitroaryl sulfones will be found to react with most of the reagents that are capable of displacing the halogen of an *o*-halonitrobenzene. *o*-Nitrophenyl phenyl sulfone is known to hydrolyze readily with alcoholic sodium hydroxide.

$$C_6H_5SO_2C_6H_4NO_2\text{-}o + p\text{-}CH_3C_6H_4OK \rightarrow C_6H_5SO_2K + o\text{-}O_2NC_6H_4OC_6H_4CH_3\text{-}p$$

Coats and Gibson[165] have found that the rearrangement of hydroxy sulfones to sulfinic acids is reversible, the extent of the reverse reaction depending upon the alkalinity of the solution. The optimum *p*H for sulfone formation varies from one sulfinic acid to another. Some of the acids rearrange when recrystallized from acetone. However, β-*o*-nitrophenoxyethanesulfinic acid showed no tendency to revert to the sulfone. For the other compounds, substituents that facilitate sulfinic acid formation from the hydroxy sulfones also assist the reverse reaction.

Hinsberg has reported[166] that certain dihydroxynaphthyl sulfones upon heating go to quinone sulfoxides. In view of the unusual difficulty encountered in attempts to reduce the sulfone group this interpretation of the reaction seems open to question.



In a study of the alkylation of bis-(4-hydroxyphenyl) sulfone[9] it was found that ether formation occurred more slowly than it does for the bis-(4-hydroxyphenyl)-methane. This was believed to be due to the higher acidity of the sulfone. A detailed comparison of the rates at which alkoxy sulfones, $(p\text{-}ROC_6H_4)_2SO_2$, and ketones, $(ROC_6H_4)_2CO$, undergo halogenation[167] showed that the ketones substituted about forty times as rapidly as the sulfones. In other words the sulfone group greatly inactivates a *meta* hydrogen atom, which is in accord with the behavior of other strongly *meta*-directing groups.

There has been considerable interest in bis-(*p*-hydroxyphenyl) sulfone as a starting material for the preparation of tanning agents and resinous substances. Products obtained from the sulfone and glycollic acid,[168] formaldehyde,[169] formaldehyde and sodium sulfite,[170] urea and formaldehyde,[171] and ligninsulfonic acid and formaldehyde,[172] have been described in the patent literature. In addition, condensation of the product obtained from crude tolylsulfones and phenolsulfonic acids with formaldehyde[173] and of bis-(hydroxyaryl) sulfone sulfonic acids with formaldehyde are claimed to produce tanning agents.

AMINO SULFONES

α-Aminoalkyl Sulfones. The only α-aminoalkyl sulfones on record are those resulting from the reaction of hydroxymethyl phenyl sulfone with ammonia and aniline.[181] Attempts to obtain an aminomethyl sulfone by hydrolysis of the phthalimido compound led to complete decomposition;[174] formaldehyde was the only product isolated.

β- and γ-Aminoalkyl Sulfones. If the reaction is carried out in acid solution a β-aminoalkyl alkyl sulfide can be oxidized to the sulfone with permanganate[174] without affecting the amino group. Methyl β-aminoethyl sulfone, the ethyl homolog, methyl γ-aminopropyl sulfone,[175] methyl δ-aminobutyl sulfone[176] and α-amino-β-methylsulfonylpropane[177] have been prepared in this manner. Two of these sulfones have also been obtained from hydrolysis of the naturally occurring mustard oils: γ-methylsulfonylpropyl isothiocyanate (cheiroline)[178] and δ-methylsulfonylbutyl isothiocyanate (erysoline).[176]

Several bis-(β-alkylaminoethyl) sulfones have been prepared by the action of an amine upon bis-(β-chloroethyl) sulfone.[179] The reaction is surprisingly vigorous; mixing the reactants in alcohol solution in the presence of sodium carbonate causes the solution to boil within 2 minutes. The sulfide and sulfoxide halogens do not show this behavior.

β-Aminoethyl and γ-aminopropyl phenyl sulfones have been synthesized by reactions of the Gabriel type.[180] The yields are good. The preparation of bis-(β-aminoethyl) sulfone and bis-(γ-aminopropyl) sulfone[180] have been accomplished by a variation of this procedure.

$$C_6H_4(CO)_2NCH_2CH_2Br \xrightarrow{C_6H_5SO_2Na}$$

$$C_6H_4(CO)_2NCH_2CH_2SO_2C_6H_5 \xrightarrow[CH_3COOH]{HCl} H_2NCH_2CH_2SO_2C_6H_5$$

$$[C_6H_4(CO)_2NCH_2CH_2]_2S \xrightarrow{CrO_3} [C_6H_4(CO)_2NCH_2CH_2]_2SO_2 \xrightarrow{KOH}$$
$$[o\text{-}C_6H_4(COOK)CONHCH_2CH_2]_2SO_2 \xrightarrow{HCl} (H_2NCH_2CH_2)_2SO_2$$

Secondary amines always result through the action of β-chloroethyl aryl sulfones with ammonia.[117] β-Hydroxyethyl methyl sulfone[181] gives a mixture of amines.

$$CH_3SO_2CH_2CH_2OH \xrightarrow{NH_3}$$
$$CH_3SO_2CH_2CH_2NH_2 + (CH_3SO_2CH_2CH_2)_2NH + H_2O$$

The preparation of various β-diethylaminoethyl aryl sulfones from β-chloroethyldiethylamine and a sodium sulfinate has been described in the patent literature.[182a]

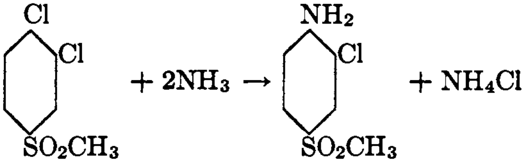
Methyl β-aminoethyl sulfone[174] is a hygroscopic liquid which is not volatile with steam and could not be distilled under reduced pressure. The quaternary ammonium iodide decomposes when warmed with alkali but the vinyl methyl sulfone was not isolated.

The oxidation of γ-aminopropyl methyl sulfone with permanganate at 100° gives β-methylsulfonylpropionic acid.[175] With fuming nitric acid at 200° the only product isolated was methanesulfonic acid. Heating with phosphorus and hydrogen iodide at 250° resulted in complete decomposition to hydrogen sulfide, ammonia, and volatile hydrocarbons. Many derivatives of the sulfone have been made by reactions involving the amino group.[182b] A study of the physiological action of β-aminoethyl and γ-aminopropyl phenyl sulfone showed that the latter was the more toxic.[183]

Aminoaralkyl and Aryl Sulfones: Preparation. Sulfones having an amino group attached to the benzene nucleus have been prepared in several ways. Benzylsulfonylsalicylic acid and related compounds[184] nitrate in the benzyl group and reduction of the nitro compounds gives amines of value as dye intermediates. Other aminobenzyl aryl sulfones have been prepared by reduction of nitro compounds obtained in various ways.[185] A series of bis-(*p*-dimethylaminophenyl)-carbinyl aryl sulfones[59b] has been synthesized from the reaction of a sulfinic acid and the carbinol.

$$[(CH_3)_2NC_6H_4]_2CHOH + C_6H_5SO_2H \rightarrow$$
$$[(CH_3)_2NC_6H_4]_2CHSO_2C_6H_5 + H_2O$$

Aminoaryl alkyl sulfones have been prepared from the nitroaryl sulfones described earlier.[93,186] The action of ammonia or aniline upon 2-nitro-4-alkylsulfonylchlorobenzenes replaces the halogen[187] easily to give the amine. If a 3,4-dichlorophenyl alkyl sulfone is heated with ammonia or an amine the halogen *para* to the sulfone linkage is replaced.[188]



However, only the *para* halogen needs to be present.[189a] The amine may be anthranilic acid.[189b] Quaternary aminoaryl sulfones of the general formula $p\text{-}[R_3N(Cl)]C_6H_4SO_2CHR'R''$ where R′ or R″ is a long-chain alkyl group have also been made from the halogen compounds[190] and a secondary amine followed by methylation with methyl sulfate.

Amino derivatives of sulfones containing only aryl groups have been studied intensively in recent years because of their value as medicinals.

4-Nitrophenyl 4-aminophenyl sulfone[191] has been prepared by oxidation of the N-acetylated sulfide with hydrogen peroxide followed by hydrolysis. 4-(4-Aminophenylsulfonyl)-benzenesulfonamide[192] may be made from sulfanilamide by the sequence of reactions shown in the equations.

$$NH_2C_6H_4SO_2NH_2 \rightarrow ClN_2C_6H_4SO_2NH_2 \xrightarrow{NaSC_6H_4NO_2} NO_2C_6H_4SC_6H_4SO_2NH_2 \rightarrow NO_2C_6H_4SO_2C_6H_4SO_2NH_2 \rightarrow NH_2C_6H_4SO_2C_6H_4SO_2NH_2$$

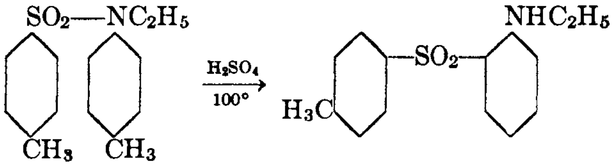
The preparation of a group of aminoaryl sulfones of interest as dye intermediates[193] depends upon the reaction of a sodium sulfinate with an aryl halide containing a halogen activated by nitro and sulfonic acid groups, followed by reduction.

A series of *o*-aminophenyl aryl sulfones has been prepared by the action of a sodium sulfinate upon an *o*-halogenated azo compound[194] followed by reduction. Apparently the azo group exerts an activating

$$o\text{-}ClC_6H_4N{=}NC_6H_4OH \rightarrow o\text{-}(C_6H_5SO_2)C_6H_4N{=}NC_6H_4OH \rightarrow o\text{-}(C_6H_4SO_2)C_6H_4NH_2$$

influence on the halogen, comparable to that of carboxyl.

A number of aminoaryl sulfones have been obtained by the action of concentrated sulfuric acid upon sulfonamides of secondary amines.[195] The amides from primary amines undergo hydrolysis and sulfonation



under the same conditions. This rearrangement has been shown to proceed with *m*-nitrobenzenesulfon-N-methyl-*p*-toluidide[196] to the extent of 83%, 17% undergoing hydrolysis. In a similar manner 2-methylamino-4-methylphenyl 2-nitrophenyl sulfone[197] has been obtained from the corresponding sulfonamide.[198]

The aryl sulfones having an amino group attached to each benzene ring have been made by the action of ammonia on the halogen compounds,[199] the action of thionyl chloride upon acetanilide followed by oxidation and hydrolysis,[200] by reduction of the dinitro sulfone,[201] or

$$C_6H_5NHCOCH_3 \xrightarrow{SOCl_2} (CH_3CONHC_6H_4)_2SO \xrightarrow{CrO_3} (CH_3CONHC_6H_4)_2SO_2 \rightarrow (NH_2C_6H_4)_2SO_2$$

of the nitrophenyl acetaminophenyl sulfone[202] followed by hydrolysis, and by oxidation of the bis-(acetylaminoaryl) sulfide[203] followed by hydrolysis. Several unsymmetrical compounds, $RCONHC_6H_4SO_2C_6H_4NHCOR'$, have also been prepared from the sulfides or sulfoxides.[203c] Several piperidino derivatives of aryl sulfones have been prepared in determining the presence of activated halogen in nitroaryl sulfones.[204a] *p*-Acylaminophenyl *p*-hydroxyphenyl sulfones have been

$$4\text{-}BrC_6H_4SO_2C_6H_3(NO_2)Cl\text{-}3,4 + 2C_5H_{10}NH \rightarrow 4\text{-}BrC_6H_4SO_2C_6H_3(NO_2)NC_5H_{10}\text{-}3,4 + C_5H_{10}NH_2Cl$$

described in a patent.[204b]

Reactions and Properties of Aminoaryl Sulfones. Since the sulfone group is inert toward most reagents the reactions of the aminoaryl sulfones are not essentially different from those of other aromatic amines. Bis-(*p*-aminophenyl) sulfone has been condensed with formaldehyde sodium bisulfite[205] and also the cinnamic aldehyde derivative,[206] reaction occurring as indicated. Allyl isothiocyanate gives the

$$2C_6H_5CH{=}CHCHO + 4NaHSO_3 + (H_2NC_6H_4)_2SO_2 \rightarrow [C_6H_5CH(SO_3Na)CH_2CH(SO_3Na)NHC_6H_4]_2SO_2 + 2H_2O$$

bis-(allyl thiourea). A number of acyl derivatives and Schiff's bases have also been made.[207a] Carbonyl chloride yields the isocyanate.[207b]

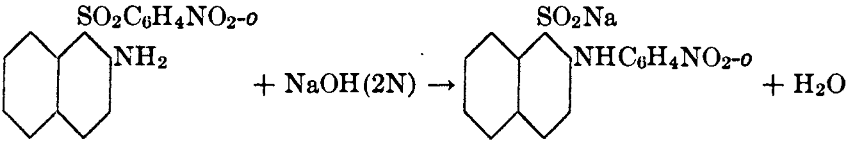
The amine has been converted into the azide[208] and diazotized and coupled with tyrosine and with proteins.[209] Coupling the diazo compound with a phenol and observing the intensity of the color produced constitutes an analytical procedure for the aminoaryl sulfone or its acetyl derivative in urine.[210] Heterocyclic compounds have also been prepared from the sulfone.[211]

It was found by several investigators[212] that bis-(*p*-aminophenyl) sulfone is more effective as a cure for β-hemolytic streptococcus infections in mice than is sulfanilamide but the toxicity is also higher.[203a, 213] The acylamino compounds show a lower toxicity than sulfanilamide. They are hydrolyzed in the body to the amino compound.[214] Conversely when the bis-(*p*-aminophenyl) sulfone is given it appears in the urine partly in its acetylated form.[215] This acetamino compound gives a color with *p*-cresoltyrosinase.[216]

The effectiveness of bis-(*p*-aminophenyl) sulfone in the treatment of pneumonia has received considerable attention.[217] This compound has been reported[218] also to slow the growth of tuberculosis bacillus cultures.

The bactericidal activity of *p*-aminophenyl alkyl sulfones[219] increases as the alkyl changes from methyl to *n*-propyl and then drops off again for the higher groups. Branching of the alkyl carbon chain has an unfavorable effect.

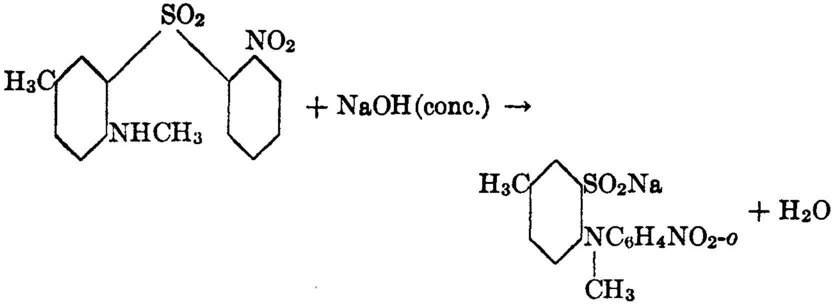
Rearrangement of Nitroaryl Aminoaryl Sulfones. Diaryl sulfones with an *o*-amino group in one ring and an *o*-nitro group in the other are converted by aqueous alkali into sulfinic acid derivatives of diarylamines,[220] a reaction closely related to that undergone by *o*-hydroxyaryl sulfones under the same conditions (see p. 697).

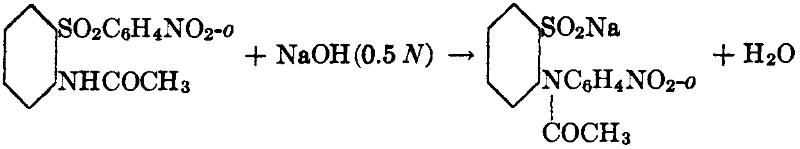


As might be anticipated an *o*-nitrophenyl aryl sulfone reacts with aniline.[221] Replacing one of the amine hydrogens with methyl or acetyl[222] does not interfere with the reaction when the amine and

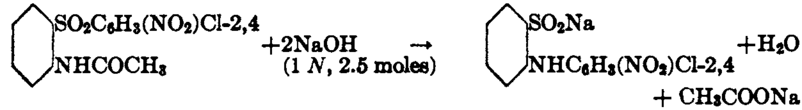
$$o\text{-}C_6H_5SO_2C_6H_4NO_2 + C_6H_5NH_2 \rightarrow o\text{-}C_6H_5NHC_6H_4NO_2 + C_6H_5SO_2H$$

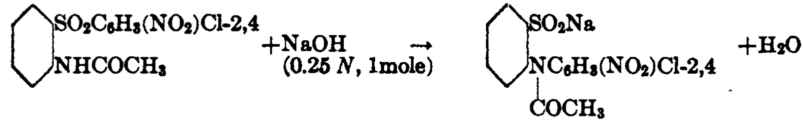
sulfone groups are in the same molecule. If the acetaminoaryl sulfone is boiled with an excess of 1 *N* alkali the product is sodium 2-(2-

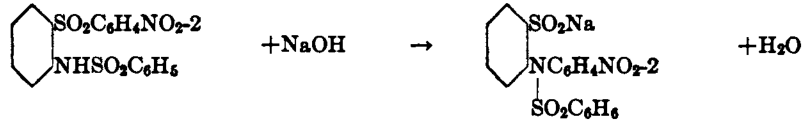


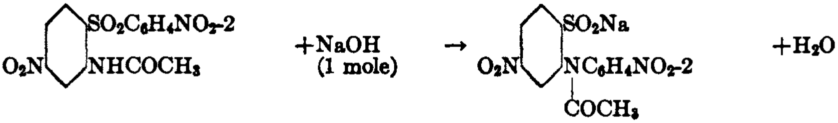


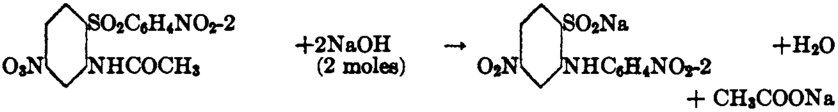
nitrophenylamino)-benzenesulfinate. The results obtained with other aminoaryl sulfones are shown by the equations.



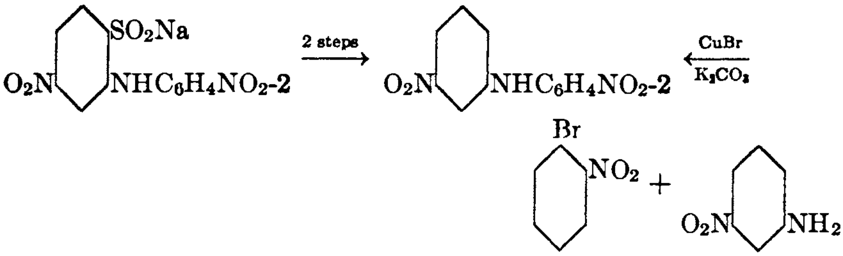








The sodium sulfinates were characterized in each instance by conversion to sulfones by methylation. The structure of one of them was determined by degradation to a sulfur-free arylamine.



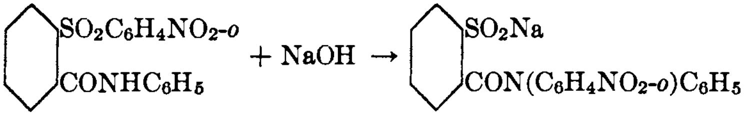
The conditions necessary for rearrangement to occur are also present in *o*-nitrophenylsulfonylacetanilide,[223] the intermediate sulfinic acid readily losing sulfur dioxide. A *m*-nitro group in the anilide

$$o\text{-}O_2NC_6H_4SO_2CH_2CONHC_6H_5 \xrightarrow{NaOH} [o\text{-}O_2NC_6H_4N(C_6H_5)COCH_2SO_2H] \rightarrow o\text{-}O_2NC_6H_4N(C_6H_5)COCH_3 + SO_2$$

ring does not affect the reaction but with an additional methylene group between the sulfur and nitrogen only hydrolysis occurs. Unexpectedly the sulfone group hydrolyzed at the aliphatic rather than

$$o\text{-}O_2NC_6H_4SO_2CH_2CH_2CONHC_6H_5 + NaOH \rightarrow o\text{-}O_2NC_6H_4SO_2Na + HOCH_2CH_2CONHC_6H_5$$

the aromatic carbon, a reaction analogous to the behavior of γ-disulfones toward alkali. If the two intervening carbons between the sulfone and amide linkage are aromatic the rearrangement proceeds normally.



SULFONYL DERIVATIVES OF ACIDS, ESTERS, AMIDES, AND CYANIDES

Compounds containing the sequence of atoms RSO_2CH_2X, where X is a cyanide, acyl, carboxyl, or other similar group and R is alkyl or aryl, exhibit in varying degree the properties characteristic of substances containing acidic methylene hydrogen. The compounds of this type which have been investigated are numerous but the results may for the most part be presented briefly in tabular form.

Sulfonyl Carboxylic Acids. Sulfones containing the carboxyl group have been prepared by oxidation of the corresponding sulfides.[224] For example, oxidation of α-(*tert*-butylthiol)-propionic acid with permanganate in slightly alkaline solution gave a 96.5% yield of the sulfone.[224b] Alkyl arylsulfonylacetates have also been made by the reaction of a sodium sulfinate with α-halogen esters.[225] Ethyl *p*-tolylsulfonylacetate is formed by allowing ethyl α-chloroacetoacetate and sodium *p*-toluenesulfinate to stand in alcohol solution for two weeks.[226] If the solution is boiled this reaction becomes of minor importance, another predominating.

$$C_6H_5SO_2Na + ClCH_2COOC_2H_5 \rightarrow C_6H_5SO_2CH_2COOC_2H_5 + NaCl \text{ (80\% yield)}$$

$$p\text{-}C_7H_7SO_2Na + CH_3COCHClCOOC_2H_5 + C_2H_5OH \rightarrow CH_3COOC_2H_5 + p\text{-}C_7H_7SO_2CH_2COOC_2H_5 + NaCl$$

$$CH_3COCHClCOOC_2H_5 + p\text{-}C_7H_7SO_2Na + 2C_2H_5OH \rightarrow CH_3COCH_2COOC_2H_5 + p\text{-}C_7H_7SO_3Na + HCl + (C_2H_5)_2O$$

Similar results were obtained with ethyl chloromalonate. The reaction of *p*-toluenesulfonyl chloride with ethyl sodiomalonate in the presence of excess sodium ethoxide gives a small yield of a disodium salt which upon acidification yields ethyl tolylsulfonylacetate.

$$p\text{-}C_7H_7SO_2Cl + NaCH(COOC_2H_5)_2 \xrightarrow{NaOC_2H_5} p\text{-}C_7H_7SO_2C(Na)(COONa)COOC_2H_5 \xrightarrow{HCl} p\text{-}C_7H_7SO_2CH_2COOC_2H_5$$

Despite earlier reports[227] of difficulty in preparing ethyl α-phenylsulfonylbutyrate by alkylation of ethyl phenylsulfonylacetate this reaction has also proved useful in preparing sulfonyl esters and the corresponding acids.[225b]

The activating influence of the sulfone group in alkyl and arylsulfonyl acids and esters has been shown in many ways. It has already been mentioned in connection with the synthesis of simple sulfones that acids of the general formula RSO_2CH_2COOH lose carbon dioxide when heated (see pp. 678–680). Determination of the ionization constants of a number of alkylsulfonylacetic and propionic acids, prepared by oxidation of the corresponding sulfides, gave values for $K_\alpha^{25°}$ some twenty times as large as those of the sulfide acids.[224a] The data are summarized in Table XVI.

TABLE XVI

Compound	M.P., °C.	$K_\alpha^{25°} \times 10^4$
$CH_3SO_2CH_2COOH$	115	43.3
$CH_3SO_2CHCH_3COOH$	96.6	36.0
$C_2H_5SO_2CHCH_3COOH$	62.6	32.5

A study of the kinetics of the bromination and racemization reactions for α-methyl- and α-ethylsulfonylpropionic acids gave results [224c] which support the theory of a common mechanism for these reactions. At 35° in 1 *N* hydrobromic acid with excess bromine the reaction is first order but with only one equivalent of the halogen the value of *K* decreases with time. At 25.15° the rate of racemization is 0.273×10^{-3} compared with 0.249×10^{-3} for the bromination.

Ethyl phenylsulfonylacetate was first investigated by Michael and Comey.[225a] With sodium ethoxide it forms a sodium salt which crystallizes readily from cold alcohol. This is quite soluble in water, acidification yielding the original ester. Heating the ester with aqueous sodium hydroxide and acidifying the solution gives phenylsulfonylacetic acid. The sodium salt of the ester reacts readily with benzyl chloride and the alkylation may be repeated. Heating the benzyl derivative with sodium ethoxide to 100° converts it into sodium cinnamate.

$$\mathrm{C_6H_5CH_2CH(SO_2C_6H_5)COOC_2H_5 + 2C_2H_5ONa \rightarrow}$$
$$\mathrm{(C_2H_5)_2O + C_6H_5SO_2Na + C_6H_5CH{=}CHCOONa + C_2H_5OH}$$

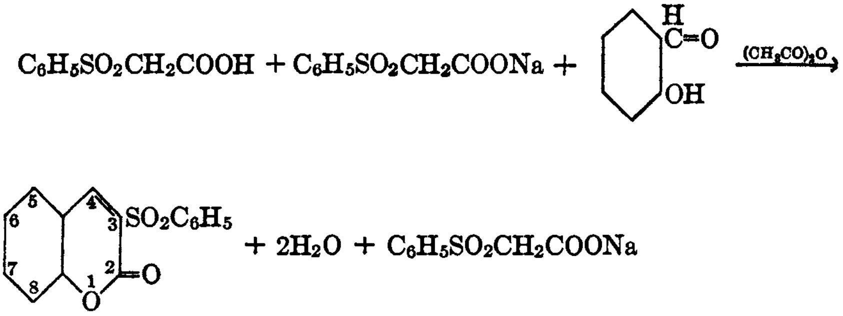
Hydrolysis with aqueous alkali is extremely slow for the esters of both the mono- and dibenzyl compounds.

It has been reported [227] that alkyl phenylsulfonylacetates do not condense with amyl nitrite and sodium ethoxide, while the corresponding nitriles and amides do react. The esters condense with benzenediazonium salts in alkaline solution,[228] however.

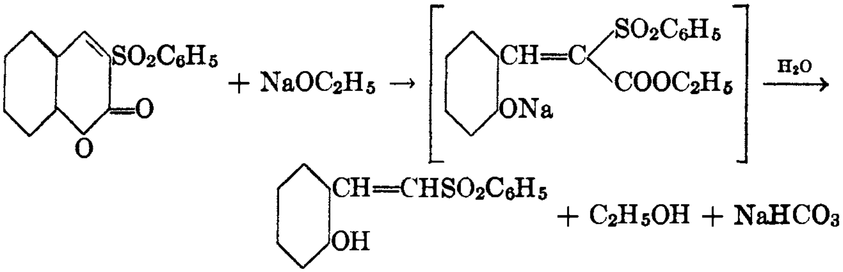
$$\mathrm{C_6H_5SO_2CH_2COOC_2H_5 + C_6H_5N_2Cl + NaOH \rightarrow}$$
$$\mathrm{C_6H_5SO_2C({=}NNHC_6H_5)COOC_2H_5 + NaCl + H_2O}$$

α-Phenylsulfonylbutyric acid [225b] has been resolved into its optical isomers by separation of the brucine salts. At 27° the half-life period of racemization for the *l*-acid in absolute alcohol is 1350 hours whereas that of the ethyl ester is 80 hours. Under the influence of sodium ethoxide the ester is racemized completely at once. This behavior suggests an enolization mechanism involving either the ester or sulfone group. The optical instability of β-disulfones discussed later indicates such an enolization involving the sulfone group to be quite possible.

Phenylsulfonylacetic acid and the *p*-methyl- and *p*-chloro derivatives condense readily with aldehydes under the usual conditions for the Perkin reaction. With an *o*-hydroxyaldehyde ring formation to a coumarin derivative occurs.[229]



By heating the product obtained from salicyaldehyde with aqueous 5% sodium hydroxide it is hydrolyzed to the starting materials. With sodium ethoxide in alcohol at 100° substances are formed which upon boiling with alkali give unsaturated sulfones.



Condensing 2,4-dihydroxybenzaldehyde with the sulfonylacetic acids as above yields 7-acetoxycoumarin derivatives. These with 5% aqueous sodium hydroxide do not regenerate the starting materials but give the unsaturated sulfones. Typical substances obtained in these investigations are listed in Table XVII. In addition, coumarin derivatives were obtained by condensing 2,4,5-, 2,4,6-, and 3,4,5-trihydroxybenzaldehyde, and 2-hydroxy-, 2,6-dihydroxy, and 2,7-dihydroxy-1-naphthaldehyde with phenyl, *p*-chlorophenyl-, and

TABLE XVII

Compound	M.P., °C.
3-Phenylsulfonylcoumarin	217–217.5
3-*p*-Tolylsulfonylcoumarin	221
3-*p*-Chlorophenylsulfonylcoumarin	242
3-Phenylsulfonyl-7-acetoxycoumarin	237
3-Phenylsulfonyl-7-hydroxycoumarin	. . .
3-*p*-Tolylsulfonyl-7-acetoxycoumarin	234
3-*p*-Tolylsulfonyl-7-hydroxycoumarin	239
3-*p*-Chlorophenylsulfonyl-7-acetoxycoumarin	224
3-*p*-Chlorophenylsulfonyl-7-hydroxycoumarin	226

p-tolylsulfonylacetic acids. Of the aldehydes studied the 2-hydroxy-1-naphthaldehyde reacted most rapidly. Numerous derivatives of these compounds were prepared.

Nitration of phenylsulfonylacetic acid[230] produces almost entirely the *meta* isomer. This is readily decarboxylated by heating.

An attempt to prepare phenylsulfonylchloroacetic acid by the action of sodium benzenesulfinate upon sodium dichloroacetate[231] gave chloromethyl phenyl sulfone. With α,α-dichloropropionic acid the reaction for the most part follows another course.

$$\mathrm{CHCl_2COONa + C_6H_5SO_2Na + H_2O \rightarrow C_6H_5SO_2CH_2Cl + NaCl + NaHCO_5}$$

$$\mathrm{CH_3CCl_2COONa + 2C_6H_5SO_2Na + H_2O \rightarrow (C_6H_5SO_2CH_2)_2 + 2NaCl + NaHCO_3}$$

α-Bromo-α-(*tert*-butylsulfonyl)-propionic acid,[224b] prepared by bromination, decomposes rapidly at 100° into isobutylene, α-bromopropionic acid, and sulfur dioxide. In aqueous hydrobromic acid hydrolysis to

$$\mathrm{CH_3C(Br)(SO_2C_4H_9)COOH \rightarrow CH_3CHBrCOOH + SO_2 + C_4H_8}$$

t-butyl alcohol takes place.

$$\mathrm{CH_3C(Br)(SO_2C_4H_9)COOH + H_2O \rightarrow (CH_3)_3COH + [HO_2SC(Br)CH_3COOH]}$$

The sulfinic acid loses sulfur dioxide to give α-bromopropionic acid and the resulting sulfurous acid reduces part of the original bromosulfonyl acid. The bromosulfonyl acid is also reduced by aqueous

$$\mathrm{CH_3C(Br)(SO_2C_4H_9)COOH + H_2CO_3 + H_2O \rightarrow CH_3CH(SO_2C_4H_9)COOH + H_2SO_4 + HBr}$$

potassium iodide indicating the strongly positive nature of the bromine.

A β-sulfonyl carboxylic acid has been prepared from cinnamic acid and benzenesulfinic acid,[232a] and by loss of carbon dioxide from the addition product of maleic acid and benzenesulfinic acid.

Recently the sulfone of *dl*-methionine has been obtained by oxidation of the amino acid with hydrogen peroxide.

A number of aliphatic sulfones containing two carboxyl groups is known. Preparation of these has been effected by oxidation of the corresponding sulfide and by the addition of a sulfinic acid to maleic acid.[232b] Sulfonyldiacetic acid results in high yield by oxidation of the sulfide with potassium permanganate in the presence of magnesium chloride.[233,234] The ethyl ester has been recommended[234] as a useful reagent for the identification of the lower-molecular-weight *n*-alkyl primary amines. Some complex cobalt salts of the acid have been investigated.[235]

$$O_2S(CH_2COOC_2H_5)_2 + 2RNH_2 \rightarrow O_2S(CH_2CONHR)_2 + 2C_2H_5OH$$

A series of investigations of α-sulfonyl diacids of the general type $[RCH(COOH)]_2SO_2$ has shown [236] that these racemize readily. The propionic acid derivative could be obtained in active forms only by the "cold crystallization" method. The free acid racemizes very quickly in water but is relatively stable in ether solution. The rate of racemization of active forms of the acids decreases with increase in size of the alkyl group. Thus, under the same conditions the α-sulfonyldibutyric acid has a half-life in water of 5 hours while for the isovaleric acid derivative this is 80 hours. Data for determining the effect of branching of the chain as compared with lengthening it are not available as yet.

As might be anticipated, the active forms of β-sulfonyldibutyric acid [237] showed little tendency to racemize. Acids containing two sulfone groups are discussed under disulfones.

α-Sulfonylacetonitriles. Derivatives of acetonitrile of which phenylsulfonylacetonitrile is the prototype have been accorded a thorough investigation by Tröger and co-workers. Those in which the —CH_2CN group is unsubstituted have been obtained by the action of sodium sulfinates upon chloroacetonitrile [238] in alcohol at 100° in a sealed tube. The tabulation for compounds prepared in this manner is given in Table XVIII. The yields are apparently good except

$$ArSO_2Na + ClCH_2CN \rightarrow ArSO_2CH_2CN + NaCl$$

TABLE XVIII

SULFONE	M.P., °C.
$C_6H_5SO_2CH_2CN$	114
o-$CH_3C_6H_4SO_2CH_2CN$	Oil
m-$CH_3C_6H_4SO_2CH_2CN$	168
p-$CH_3C_6H_4SO_2CH_2CN$	146
p-$ClC_6H_4SO_2CH_2CN$	169
p-$BrC_6H_4SO_2CH_2CN$	194
p-$IC_6H_4SO_2CH_2CN$	213–214
o-$CH_3OC_6H_4SO_2CH_2CN$	84–85
p-$CH_3OC_6H_4SO_2CH_2CN$	115
p-$C_2H_5OC_6H_4SO_2CH_2CN$	140–141
1,2,4,5-$(CH_3)_3C_6H_2SO_2CH_2CN$	110–111
α-$C_{10}H_7SO_2CH_2CN$	109
β-$C_{10}H_7SO_2CH_2CN$	95
m-$C_6H_4(SO_2CH_2CN)_2$	164
1,2,4-$CH_3C_6H_3(SO_2CH_2CN)_2$	179

for the preparation of *m*-benzenedisulfonylacetonitrile. A similar series of sulfones[239] (see Table XIX) has been prepared from α-chloropropionitrile and sodium sulfinates by heating the reactants together in a sealed tube at 130–140°.

TABLE XIX

Sulfone	M.P., °C.
$C_6H_5SO_2CH(CH_3)CN$	72
p-$CH_3C_6H_4SO_2CH(CH_3)CN$	66
p-$ClC_6H_4SO_2CH(CH_3)CN$	101–102
p-$BrC_6H_4SO_2CH(CH_3)CN$	98
p-$IC_6H_4SO_2CH(CH_3)CN$	115
β-$C_{10}H_7SO_2CH(CH_3)CN$	90–91

These compounds form sodium salts which are decomposed by carbonic acid. The derivatives of propionitrile are, however, much less soluble in aqueous alkali than are the compounds derived from acetonitrile. No procedure has been devised for reducing them to β-sulfonylethylamines but most other reactions of the cyanide group occur normally. With alcohol imino esters result.

$$ArSO_2CH_2CN + C_2H_5OH + HCl \rightarrow ArSO_2CH_2C({=}NH_2Cl)OC_2H_5$$

Hydrogen sulfide adds to give thioamides.

$$ArSO_2CH_2CN + H_2S \xrightarrow{NH_3} ArSO_2CH_2CSNH_2$$

Hydroxylamine also adds readily.

$$ArSO_2CH_2CN + H_2NOH \rightarrow ArSO_2CH_2C(NH_2)NOH$$

Alkylation of these amidoximes replaces the hydrogen of the oxime group.[240] Hydrolysis of the nitriles with acid or alkali yields the corresponding acids. If both hydrogens of the methylene group are replaced by alkyl this reaction proceeds with difficulty or not at all.[241] Phenylsulfonylacetonitrile or the α-methyl derivative with 0.1 *N* sodium hydroxide at 100° gives about 68% of the sodium salt of the acid before loss of the carboxyl group becomes marked.[239] Hydrolysis does not stop at the amide stage for any of these nitriles. The hydrogen sulfide and hydroxylamine reactions are slow for the dialkyl compounds. Phenylmagnesium bromide is said to give no reaction with phenylsulfonylacetonitrile.[242] Formation of benzene and a magnesium salt of the sulfone would be expected.

Alkylation of the sulfonylacetonitriles with alkyl halides and sodium ethoxide in alcohol[241] yields dialkyl derivatives readily. A monoalkyl compound has apparently been obtained in only one instance by this type of reaction, by benzylation of β-naphthylsulfonylacetonitrile. The sulfonyldialkylacetonitriles are listed in Table XX.

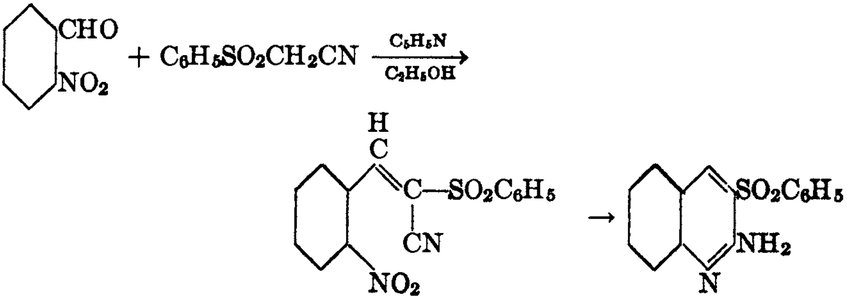
TABLE XX

SULFONE	M.P., °C.
$C_6H_5SO_2C(C_2H_6)_2CN$	78
$C_6H_5SO_2C(i\text{-}C_3H_7)_2CN$	Brown oil (impure?)
$C_6H_5SO_2C(CH_2C_6H_5)_2CN$	157-157.5
$p\text{-}ClC_6H_4SO_2C(C_2H_5)_2CN$	81
$p\text{-}ClC_6H_4SO_2C(n\text{-}C_3H_7)_2CN$	Oil
$p\text{-}ClC_6H_4SO_2C(i\text{-}C_3H_7)_2CN$	Oil
$p\text{-}ClC_5H_4SO_2C(CH_2C_6H_5)_2CN$	125
$p\text{-}BrC_6H_4SO_2C(C_2H_5)_2CN$	94
$p\text{-}BrC_6H_4SO_2C(CH_2C_6H_5)_2CN$	145
$p\text{-}IC_6H_4SO_2C(CH_2C_6H_5)_2CN$	166
$o\text{-}CH_3OC_6H_4SO_2C(C_2H_5)_2CN$	Oil
$o\text{-}CH_3OC_6H_4SO_2C(CH_2C_6H_5)_2CN$	123
$p\text{-}CH_3OC_6H_4SO_2C(CH_2C_6H_5)_2CN$	119
$p\text{-}C_2H_5OC_6H_4SO_2C(C_2H_5)_2CN$	81
$p\text{-}C_2H_5OC_5H_4SO_2C(CH_2C_6H_5)_2CN$	119
$1,2,4,5\text{-}(CH_3)_3C_6H_2SO_2C(C_2H_5)_2CN$	Oil
$\alpha\text{-}C_{10}H_7SO_2C(CH_3)_2CN$	115
$\alpha\text{-}C_{10}H_7SO_2C(CH_2C_6H_5)_2CN$	180
$\beta\text{-}C_{10}H_7SO_2C(CH_3)_2CN$	115
$\beta\text{-}C_{10}H_7SO_2C(C_2H_5)_2CN$	Transparent resin
$\beta\text{-}C_{10}H_7SO_2C(CH_2C_6H_5)_2CN$	177
$\beta\text{-}C_{10}H_7SO_2CH(CH_2C_6H_5)CN$	128

Condensation of the sulfonylacetonitriles with aromatic aldehydes takes place readily in the presence of a trace of alkali.[243] The compound from methylsulfonylacetonitrile and *p*-dimethylaminobenzaldehyde has been patented as a dye.[244]

$$C_6H_5SO_2CH_2CN + C_6H_5CHO \rightarrow C_6H_5SO_2C({=}CHC_6H_5)CN + H_2O$$

The wide applicability of the reaction is shown by the compounds prepared from arylsulfonylacetonitriles which are given in Table XXI. By using *o*-nitrobenzaldehyde and reducing the first product a quinoline derivative results.[245]

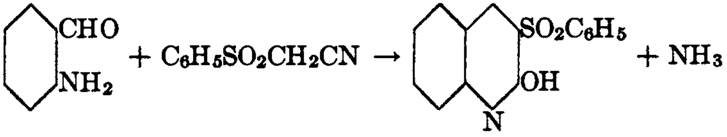


The same compound is formed directly by starting with *o*-aminobenzaldehyde. If this last reaction is carried out at 170° in a sealed tube,

TABLE XXI

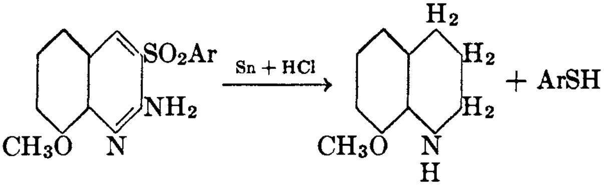
SULFONE	M.P., °C.
$C_6H_5SO_2C(=CHC_6H_6)CN$	135
$C_6H_5SO_2C(=CHC_5H_4OH\text{-}o)CN$	160
$C_6H_5SO_2C(=CHC_5H_4OH\text{-}p)CN$	214
$C_6H_5SO_2C(=CHC_6H_4OCH_3\text{-}p)CN$	113
$C_6H_5SO_2C(=CHC_6H_4NO_2\text{-}p)CN$	159
$C_6H_5SO_2C[=CHC_6H_4N(CH_3)_2\text{-}p]CN$	194
$C_6H_5SO_2C[=CHC_6H_4CH(CH_3)_2\text{-}p]CN$	78
$C_6H_5SO_2C(=CH—CH=CHC_6H_5)CN$	146
$p\text{-}CH_3C_6H_4SO_2C(=CHC_6H_5)CN$	114
$p\text{-}CH_3C_6H_4SO_2C(=CHC_6H_4OH\text{-}o)CN$	152
$p\text{-}CH_3C_6H_4SO_2C(=CHC_6H_4OH\text{-}p)CN$	133–135
$p\text{-}CH_3C_6H_4SO_2C(=CHC_6H_4OCH_3\text{-}p)CN$	110
$p\text{-}CH_3C_6H_4SO_2C(=CHC_6H_4NO_2\text{-}p)CN$	198
$p\text{-}CH_3C_6H_4SO_2C[=CHC_6H_4N(CH_3)_2\text{-}p]CN$	217
$p\text{-}ClC_6H_4SO_2C(=CHC_6H_4OH\text{-}p)CN$	154–156
$p\text{-}ClC_6H_4SO_2C[=CHC_6H_4N(CH_3)_2\text{-}p]CN$	245–246
$p\text{-}BrC_6H_4SO_2C(=CHC_6H_6)CN$	119
$p\text{-}BrC_6H_4SO_2C(=CHC_5H_4OH\text{-}o)CN$	143
$p\text{-}BrC_6H_4SO_2C(=CHC_6H_4OH\text{-}p)CN$	166
$p\text{-}BrC_6H_4SO_2C(=CHC_6H_4OCH_3\text{-}p)CN$	146
$p\text{-}BrC_6H_4SO_2C(=CHC_6H_4Br\text{-}p)CN$	210
$p\text{-}BrC_6H_4SO_2C[=CHC_6H_4N(CH_3)_2\text{-}p]CN$	240–241
$p\text{-}BrC_6H_4SO_2C(=CH—CH=CH—C_6H_5)CN$	176
$p\text{-}IC_6H_4SO_2C[=CHC_6H_4N(CH_3)_2\text{-}p]CN$	222
$2,4,5\text{-}(CH_3)_3C_6H_2SO_2C(=CHC_6H_4OH\text{-}p)CN$	181
$2,4,5\text{-}(CH_3)_3C_6H_2SO_2C[=CHC_6H_4N(CH_3)_2\text{-}p]CN$	192
$\beta\text{-}C_{10}H_7SO_2C(=CHC_6H_5)CN$	122
$\beta\text{-}C_{10}H_7SO_2C(=CHC_6H_4OH\text{-}o)CN$	173
$\beta\text{-}C_{10}H_7SO_2C(=CHC_6H_4OH\text{-}p)CN$	157
$\beta\text{-}C_{10}H_7SO_2C(=CHC_6H_4OCH_3\text{-}p)CN$	117
$\beta\text{-}C_{10}H_7SO_2C(=CHC_6H_4NO_2\text{-}p)CN$	187
$\beta\text{-}C_{10}H_7SO_2C[=CHC_6H_4N(CH_3)_2\text{-}p]CN$	197
$\beta\text{-}C_{10}H_7SO_2C[=CHC_6H_4CH(CH_3)_2\text{-}p]CN$	146
$\beta\text{-}C_{10}H_7SO_2C(=CH—CH=CH—C_6H_5)CN$	157

however, the amino group is lost giving a substituted carbostyril. Various derivatives were prepared from this and from the analogous



p-toluenesulfonyl- and *p*-chlorobenzenesulfonylcarbostyrils. 2-Amino-3-methoxybenzaldehyde has also been employed in this condensation.

Reduction of the aminoquinoline gives a thiophenol and a tetrahydroquinoline.[246, 247]



The sulfonylacetonitriles undergo condensation with amyl nitrite in the presence of sodium ethoxide.[248a]

$$C_6H_5SO_2CH_2CN + C_5H_{11}ONO \xrightarrow{C_2H_5ONa} C_6H_5SO_2C({=}NOH)CN + C_5H_{11}OH$$

No mention was made of obtaining the oximes in stereoisomeric forms. All attempts to hydrolyze the oximes to the ketones were futile. With bromine in water[248] the indicated change occurs. The bromine compounds are also obtained by direct bromination of the sulfonylacetonitriles. These reactions were performed where aryl is phenyl, *p*-chlorophenyl, *p*-bromophenyl, and *p*-iodophenyl. Attempts to hydrolyze the dibromo compounds to the ketones were unsuccessful.

$$ArSO_2C({=}NOH)CN + Br_2 + H_2O \rightarrow ArSO_2CBr_2CN + ?$$

By the action of chlorine in alkaline solution the amidoximes lose the cyanide group.[249] The dichloronitriles are obtainable, however, by chlorination of the unsubstituted sulfonylacetonitriles with "nascent chlorine" obtained by adding bleaching powder to the nitrile dissolved in acetic acid. Dry chlorine works well for phenylsulfonylacetonitrile but not for the *p*-tolyl and *p*-chlorophenyl compounds. Iodine in potassium iodide solution does not react with the oxime or methylene group in any way. The dihalogenated compounds prepared are listed below.

$$C_6H_5SO_2C(NOH)CN + Cl_2 + NaOH \rightarrow C_6H_5SO_2CHCl_2 + NaCl + H_2O + ?$$

TABLE XXII

Original Nitrile	Dichloro Compound M.P., °C.	Dibromo Compound M.P., °C.
$C_6H_5SO_2CH_2CN$	57	123
p-$ClC_6H_4SO_2CH_2CN$	96–97	126
p-$BrC_6H_4SO_2CH_2CN$	105–106	129
p-$IC_6H_4SO_2CH_2CN$	111–112	131
p-$CH_3C_6H_4SO_2CH_2CN$	92	121
o-$CH_3OC_6H_4SO_2CH_2CN$	121	123
p-$C_2H_5OC_6H_4SO_2CH_2CN$	95	118
2,4,5-$(CH_3)_3C_6H_2SO_2CH_2CN$	103–104	123
α-$C_{10}H_7SO_2CH_2CN$	118	146

Sodium benzenesulfinate reduces the halogen compounds to the original nitrile.[249, 250] No satisfactory procedure has been found for obtaining monohalo derivatives of the sulfonylacetonitriles.

$$C_6H_5SO_2CBr_2CN + 2C_6H_5SO_2Na + 2H_2O \rightarrow C_6H_5SO_2CH_2CN + 2C_6H_5SO_3Na + 2HBr$$

Ethyl nitrate does not react with phenylsulfonylacetonitrile. Attempts to oxidize the methylene to the keto group by potassium permanganate were unsuccessful.[249]

Diazonium salts react readily with the α-sulfonylaceto- and propionitriles in the presence of sodium acetate[251] in alcohol solution.

$$ArN_2Cl + Ar'SO_2CH_2CN \xrightarrow{CH_3COONa} ArN{=}N{-}CH(CN)SO_2Ar' + HCl$$

Whether the product exists as the azo compound or the hydrazone is not known. The sulfones derived from propionitrile also react, the products of necessity being the true azo compounds. In Table XXIII are listed the various substances prepared.

TABLE XXIII

Sulfonylnitrile	Diazonium Salt	Azo Compound or Hydrazone, M.P., °C.
α-$C_{10}H_7SO_2CH_2CN$	$C_6H_5N_2Cl$	203
	o-$CH_3C_6H_4N_2Cl$	149–150
	p-$CH_3C_6H_4N_2Cl$	193
	p-$CH_3OC_6H_4N_2Cl$	173
β-$C_{10}H_7SO_2CH_2CN$	$C_6H_5N_2Cl$	194–195
	p-$CH_3C_6H_4N_2Cl$	189–190
	m-$CH_3C_6H_4N_2Cl$	160–161
	p-$C_2H_5OC_6H_4N_2Cl$	165–166
p-$BrC_6H_4SO_2CH_2CN$	$C_6H_5N_2Cl$	185
	p-$C_2H_5OC_6H_4N_2Cl$	154–155
$C_6H_5SO_2CH(CH_3)CN$	$C_6H_5N_2Cl$	78
	p-$CH_3C_6H_4N_2Cl$	103–104
	p-$CH_3OC_6H_4N_2Cl$	81–82
	p-$C_2H_6OC_6H_4N_2Cl$	96–97
p-$ClC_6H_4SO_2CH(CH_3)CN$	$C_6H_5N_2Cl$	90–91
	β-$C_{10}H_7N_2Cl$	154–155
p-$BrC_6H_4SO_2CH(CH_3)CN$	p-$CH_3C_6H_4N_2Cl$	151
	p-$CH_3OC_6H_4N_2Cl$	153
β-$C_{10}H_7SO_2CH(CH_3)CN$	$C_6H_5N_2Cl$	120
	p-$CH_3C_6H_4N_2Cl$	119–120

All these azo compounds are yellow or red in color except *p*-chlorophenylsulfonyl-α-benzeneazopropionitrile which is green.

Arylsulfonylacetamides. Phenylsulfonylacetamide was first obtained by the action of ammonia upon ethyl phenylsulfonylacetate.[252] Later a series of similar compounds was prepared from chloroacetamide and sodium sulfinates [238a] by heating these to 100° in alcohol solution. The compounds synthesized in this manner are given in Table XXIV.

$$C_6H_5SO_2Na + ClCH_2CONH_2 \rightarrow C_6H_5SO_2CH_2CONH_2 + NaCl$$

TABLE XXIV

SULFONE	M.P., °C.
$C_6H_5SO_2CH_2CONH_2$	156
o-$CH_3C_6H_4SO_2CH_2CONH_2$	143
m-$CH_3C_6H_4SO_2CH_2CONH_2$	146
p-$CH_3C_6H_4SO_2CH_2CONH_2$	166
p-$ClC_6H_4SO_2CH_2CONH_2$	169
p-$BrC_6H_4SO_2CH_2CONH_2$	166
p-$IC_6H_4SO_2CH_2CONH_2$	189
2,4-$(CH_3)_2C_6H_3SO_2CH_2CONH_2$	149
α-$C_{10}H_7SO_2CH_2CONH_2$	162
β-$C_{10}H_7SO_2CH_2CONH_2$	194

Some derivatives of propionamide have been prepared in an analogous manner.[239]

TABLE XXV

SULFONE	M.P., °C.
$C_6H_6SO_2CH(CH_3)CONH_2$	150
p-$CH_3C_6H_4SO_2CH(CH_3)CONH_2$	166
p-$ClC_6H_4SO_2CH(CH_3)CONH_2$	190
p-$BrC_6H_4SO_2CH(CH_3)CONH_2$	196.5
p-$IC_6H_4SO_2CH(CH_3)CONH_2$	210

α-*p*-Tolylsulfonyl-*n*-butyramide [253a] has been obtained in 80% yield from the sulfinate and α-bromobutyramide. *p*-Acetaminophenylsulfonylacetamide has been similarly prepared.[253b] The yields in this type of reaction were found [253a] to be better if the temperature of the reaction mixture was kept low but the time necessary was then so great that the procedure was not practical.

The oxidation of the corresponding sulfides with hydrogen peroxide was found to give good results in the preparation of alkylsulfonyl amides,[253, 254] the yields averaging about 75%. Compounds prepared in this way are listed in Table XXVI.

TABLE XXVI

SULFONE	M.P., °C.
$C_2H_5SO_2CH_2CONH_2$	98.5–99
n-$C_3H_7SO_2CH_2CONH_2$	104–104.5
n-$C_4H_9SO_2CH_2CONH_2$	119–119.5
$C_2H_5SO_2CH(CH_3)CONH_2$	126–126.5
n-$C_3H_7SO_2CH(CH_3)CONH_2$	122–122.5
n-$C_4H_9SO_2CH(CH_3)CONH_2$	114–114.5
$C_2H_5SO_2CH(C_2H_5)CONH_2$	168–168.5
n-$C_3H_7SO_2CH(C_2H_5)CONH_2$	137–137.5
$C_2H_5SO_2C(CH_3)_2CONH_2$	92.5–93
n-$C_3H_7SO_2C(CH_3)_2CONH_2$	99.5–100.5
n-$C_4H_9SO_2C(CH_3)_2CONH_2$	77.5–78
$C_2H_5SO_2CH(C_3H_7\text{-}n)CONH_2$	117.5–118
n-$C_3H_7SO_2CH(C_3H_7\text{-}n)CONH_2$	125–125.5
n-$C_4H_9SO_2CH(C_4H_9\text{-}n)CONH_2$	125–125.5
$C_2H_5SO_2CH(C_3H_7\text{-iso})CONH_2$	122–123.5
n-$C_3H_7SO_2CH(C_3H_7\text{-iso})CONH_2$	116–117
n-$C_4H_9SO_2CH(C_3H_7\text{-iso})CONH_2$	126.5–127
$C_2H_5SO_2CH(C_4H_9\text{-}n)CONH_2$	112–112.5
n-$C_3H_7SO_2CH(C_4H_9\text{-}n)CONH_2$	119–119.5
$C_6H_5CH_2SO_2CH_2CONH_2$	178.5–179

A number of α-arylsulfonyl amides have been obtained by alkylation of the acetamide derivative with an alkyl halide and sodium ethoxide in alcohol.[258]

$$p\text{-}C_7H_7SO_2CHNaCONH_2 + C_2H_5Br \rightarrow p\text{-}C_7H_7SO_2CH(C_2H_5)CONH_2 + NaBr$$

The alkylsulfonylacetamides are apparently somewhat less acidic than the aryl compounds, the amide group reacting about one-half as rapidly as the methylene group so that three products are formed.[255]

$$n\text{-}C_4H_9SO_2CH_2CONH_2 \xrightarrow[C_2H_5ONa]{(C_2H_5)_2SO_4} n\text{-}C_4H_9SO_2CH(C_2H_5)CONH_2 + n\text{-}C_4H_9SO_2CH_2CONHC_2H_5 + n\text{-}C_4H_9SO_2CH(C_2H_5)CONHC_2H_5$$

Phenylsulfonylacetamide does not undergo the Hofmann reaction to give the amine.[288a] The reactions that occur with bromine, according to Tröger and Hille, are indicated by the following equations.

$$C_6H_5SO_2CH_2CONH_2 + Br_2 \rightarrow C_6H_5SO_2CH_2CONHBr + HBr$$

$$C_6H_5SO_2CH_2CONHBr \xrightarrow{KOH} C_6H_5SO_2CHBrCONH_2$$

$$C_6H_5SO_2CH_2CONH_2 + 2Br_2 \xrightarrow{CH_3COOH} C_6H_5SO_2CHBrCONHBr + 2HBr$$

$$C_6H_5SO_2CHBrCONHBr + KOH \rightarrow C_6H_5SO_2CHBr_2 + ?$$

$$C_6H_5SO_2CH_2CONH_2 + Br_2 + NaOH \rightarrow C_6H_5SO_2CBr_3 + ?$$

However, the most satisfactory method of preparing the α-bromo-α-sulfonylamides is by bromination in moist carbon tetrachloride.[256a] The reactions of these bromoamides are of two types: (1) elimination of halogen and (2) elimination of the carbamide group. Which occurs depends in part on the groups present in the amide.

$$n\text{-}C_4H_9SO_2CBr(C_2H_5)CONH_2 + C_2H_5ONa \rightarrow n\text{-}C_4H_9SO_2CH(C_2H_5)CONH_2 + (CH_3CHO) + NaBr$$

$$p\text{-}C_7H_7SO_2CHBrCONH_2 + C_2H_5ONa \rightarrow p\text{-}C_7H_7SO_2CH_2Br\ (+\ ?)$$

With hydrazine and with hydriodic acid the only reaction is reduction and this is the chief change with piperidine and thiols in alkaline solution.

Chlorine and phenylsulfonylacetamide give compounds analogous to those obtained with bromine[238a] and also $C_6H_5SO_2CCl_2CONHCl$, m.p. 144°, the N-chlorine of which readily reacts with potassium iodide. The chlorination reactions[20b] of the p-tolyl- and β-naphthylsulfonylacetamides were found to be quite similar.

The α-sulfonyl amides are much less acidic than the corresponding cyanides and esters as they are insoluble in sodium hydroxide.[248] However, they condense with amyl nitrite in the presence of sodium ethoxide to yield the oximino compounds which separate as their yellow crystalline sodium salts. Attempts to condense the amides with aldehydes gave negative results.[248]

Arylsulfonylacetylurethanes and Ureas. A series of sulfones derived from acetylurethane and acetylurea has been synthesized from the sodium sulfinates and chloroacetyl compounds.[257]

$$C_6H_5SO_2Na + ClCH_2CONHCOOC_2H_5 \rightarrow C_6H_5SO_2CH_2CONHCOOC_2H_5 + NaCl$$

The compounds obtained by this procedure are listed in Table XXVII.

TABLE XXVII

Sulfone	M.P., °C.
$C_6H_5SO_2CH_2CONHCOOC_2H_5$	69
$p\text{-}CH_3C_6H_4SO_2CH_2CONHCOOC_2H_6$	103
$C_6H_5SO_2CH_2CONHCOOC_4H_9\text{-iso}$	81
$p\text{-}CH_3C_6H_4SO_2CH_2CONHCOOC_4H_9\text{-iso}$	89
$C_6H_5SO_2CH_2CONHCOOC_5H_{11}\text{-iso}$	73.5
$p\text{-}CH_3C_6H_4SO_2CH_2CONHCOOC_5H_{11}\text{-iso}$	83
$C_6H_5SO_2CH_2CONHCONH_2$	225
$p\text{-}CH_3C_6H_4SO_2CH_2CONHCONH_2$	223–224
$C_6H_5SO_2CH_2CONHCONHCH_3$	207
$p\text{-}CH_3C_6H_4SO_2CH_2CONHCONHCH_3$	220

Upon hydrolysis with alkali these compounds break down into a sulfonylacetic acid, ammonia, and carbon dioxide.

KETOSULFONES

α-Ketosulfones. There is on record only one example of an α-ketosulfone, that obtained by the action of benzoyl chloride upon potassium p-toluenesulfinate in ether solution at 110° under pressure.[258] It was stated that other acid chlorides behaved similarly but the products were not described. This compound is an oil which adds water or

$$C_6H_5COCl + p\text{-}C_7H_7SO_2K \rightarrow p\text{-}C_7H_7SO_2COC_6H_5 + KCl$$

alcohol readily; the hydrate loses its water of hydration incompletely at as high as 150°. Further investigation of these compounds would undoubtedly yield interesting results.

Phenylsulfonylacetone and Related Compounds. A number of arylsulfonylacetones have been obtained by the action of alkali sulfinates upon chloroacetone in alcohol solution.[247, 259, 260, 261]

$$ArSO_2Na + ClCH_2COCH_3 \rightarrow ArSO_2CH_2COCH_3 + NaCl$$

Derivatives of acetophenone have been synthesized in a similar manner.[261b] The compounds of this type are listed in Table XXVIII.

TABLE XXVIII

Sulfone	M.P., °C.	M.P. of Oxime, °C.
$C_6H_5SO_2CH_2COCH_3$	57	147–148
p-$ClC_6H_4SO_2CH_2COCH_3$	83	163–164
p-$BrC_6H_4SO_2CH_2COCH_3$	100	....
p-$CH_3C_6H_4SO_2CH_2COCH_3$	52	....
o-$CH_3OC_6H_4SO_2CH_2COCH_3$	65	160.5
p-$CH_3OC_6H_4SO_2CH_2COCH_3$	76.5	134
o-$C_2H_5OC_6H_4SO_2CH_2COCH_3$	59	122
p-$C_2H_5OC_6H_4SO_2CH_2COCH_3$	67.5	127
α-$C_{10}H_7SO_2CH_2COCH_3$	65	....
β-$C_{10}H_7SO_2CH_2COCH_3$	130	172
$C_6H_5SO_2CH_2COC_6H_5$	96	134
p-$ClC_6H_4SO_2CH_2COC_6H_5$	134.5	132
p-$CH_3C_6H_4SO_2CH_2COC_6H_5$	110	....
o-$CH_3OC_6H_4SO_2CH_2COC_6H_5$	79	....
p-$CH_3OC_6H_4SO_2CH_2COC_6H_5$	110	134
o-$C_2H_5OC_6H_4SO_2CH_2COC_6H_5$	99	129
p-$C_2H_5OC_6H_4SO_2CH_2COC_6H_5$	130	150
α-$C_{10}H_7SO_2CH_2COC_6H_5$	89	173

Phenylsulfonylacetone has also been obtained by the action of aqueous potassium permanganate upon a solution of acetonyl phenyl sulfide in carbon disulfide.[262] The reaction of Grignard reagents upon phenylsulfonylacetonitrile does not yield the ketone.[259]

All these sulfonyl ketones are readily soluble in cold alkali with the exception of the phenetyl and α-naphthyl compounds derived from acetophenone. They form oximes, semi-carbazones, imides, and phenylhydrazones readily but do not add hydrogen cyanide. Phenylsulfonylacetone is oxidized by potassium permanganate to benzenesulfonic acid, acetic acid, and carbon dioxide.[260] Reduction with sodium amalgam yields benzenesulfinic acid and isopropyl alcohol while with zinc and hydrochloric acid thiophenol is formed. Heating with alcoholic potassium hydroxide causes cleavage to phenyl methyl sulfone and potassium acetate.

$$C_6H_5SO_2CH_2COCH_3 + KOH \rightarrow C_6H_5SO_2CH_3 + CH_3COOK$$

Halogenation yields successively mono-, di-, and trisubstitution products in which only the methyl group has reacted.[260,263] ω-Phenylsulfonylacetophenone and its analogs, however, substitute easily in the methylene group. The methylene halogens oxidize sodium benzenesulfinate.

$$C_6H_5SO_2CH_2COC_6H_5 + 2Cl_2 \rightarrow C_6H_5SO_2CCl_2COC_6H_5 + 2HCl$$

$$C_6H_5SO_2CCl_2COC_6H_5 + 2C_6H_5SO_2Na + 2H_2O \rightarrow C_6H_5SO_2CH_2COC_6H_5 + 2C_6H_5SO_3Na + 2HCl$$

The halogen derivatives of phenylsulfonylacetone react by double decomposition.[261] The halogen derivatives of the ketosulfones are

$$ArSO_2CH_2COCH_2Br + C_6H_5SO_2Na \rightarrow ArSO_2CH_2COCH_2SO_2C_6H_5 + NaBr$$

listed in Table XXIX.

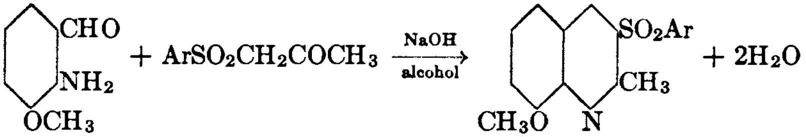
TABLE XXIX

Compound	M.P., °C.
$C_6H_5SO_2CH_2COCH_2Br$	96
$C_6H_5SO_2CH_2COCHBr_2$	113–114
$C_6H_5SO_2CH_2COCCl_3$	?
p-$ClC_6H_4SO_2CH_2COCCl_3$	119.5
p-$ClC_6H_4SO_2CH_2COCBr_3$	125.5
p-$CH_3C_6H_4SO_2CH_2COCH_2Br$	129–130
$C_6H_5SO_2CHClCOC_6H_5$	126
$C_6H_5SO_2CHBrCOC_6H_5$	138
$C_6H_5SO_2CCl_2COC_6H_5$	104
$C_6H_6SO_2CBr_2COC_6H_5$	119.5–120
p-$CH_3C_6H_4SO_2CHClCOC_6H_5$	139
p-$CH_3C_6H_4SO_2CHBrCOC_6H_5$	158
p-$ClC_6H_4SO_2CHClCOC_6H_5$	145.5–146.5
p-$ClC_6H_4SO_2CHBrCOC_6H_6$	163–164
p-$ClC_6H_4SO_2CCl_2COC_6H_5$	98–99
p-$ClC_6H_4SO_2CBr_2COC_6H_5$	121–121.5

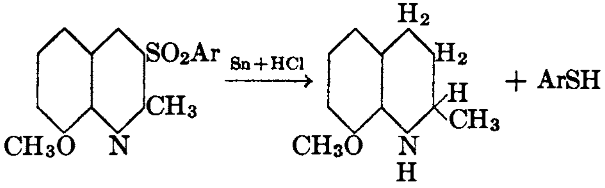
Phenylsulfonylacetone condenses with the alkyl esters of aromatic thiosulfonic acids, "disulfoxides," with the introduction of an alkylthiol group. This reaction has been useful in the preparation of sulfidesulfones.[264]

$$C_6H_5SO_2CH_2COCH_3 + p\text{-}CH_3C_6H_4SO_2SCH_3 \rightarrow C_6H_5SO_2CH(SCH_3)COCH_3 + p\text{-}CH_3C_6H_4SO_2H$$

Condensation with *o*-aminobenzaldehyde[247,261,265] or 3-methoxy-2-aminobenzaldehyde gives rise to derivatives of quinoline.

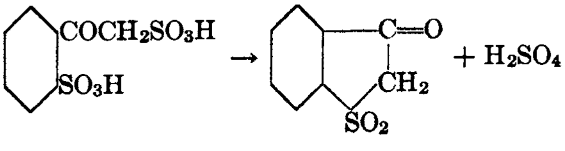


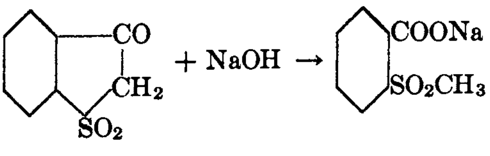
The sulfone group is not split from the ring by the action of fused potassium hydroxide nor when heated with acid under pressure. The presence of the sulfone group does not prevent the reaction of the α-methyl with aldehydes or phthalic acid. Reduction with tin and hydrochloric acid yields the thiophenol and a tetrahydroquinoline.[247,259b,261b,265]



A high reaction temperature (200°) is necessary to condense aminobenzaldehyde with sulfones derived from acetophenone to yield the β-sulfonyl-α-phenylquinolines.[259a,261b]

A cyclic β-ketosulfone, 3(2)-thianaphthenone-1-dioxide has been obtained by oxidation of the sulfide,[266] as a by-product in the sulfonation of ethyl benzoylacetate,[267] and by ring closure of acetophenone-2,ω-disulfonic acid.[268] The ketosulfone is hydrolyzed by heating with aqueous alkali to *o*-methylsulfonylbenzoic acid but is unchanged by acid.





γ-Ketosulfones. It has been mentioned earlier[108c] that benzalacetophenone condenses with *p*-tolyl benzyl sulfone to give two stereoisomeric ketosulfones. Another synthesis of a sulfone of this type involves the addition of a sulfinic acid to an unsaturated ketone.[232a]

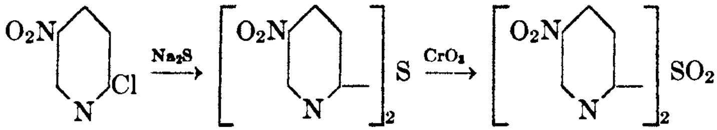
$$C_6H_5CH{=}CHCOCH_3 + p\text{-}C_7H_7SO_2H \rightarrow C_6H_5CH(SO_2C_7H_7)CH_2COCH_3$$

The reaction with cinnamalacetone occurs as shown in the equation rather than at the ends of the conjugated system.

$$C_6H_5CH{=}CHCH{=}CHCOCH_3 + C_7H_7SO_2H \rightarrow C_6H_5CH{=}CHCH(SO_2C_7H_7)CH_2COCH_3$$

PYRIDYL AND QUINOLYL SULFONES

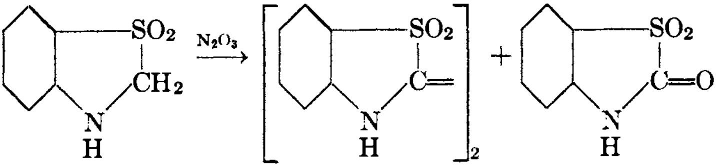
The formation of a few heterocyclic sulfones has already been described under the reactions of arylsulfonylacetones. The interest in sulfapyridine has led to the preparation of some pyridyl and quinolyl sulfones.[269a, b] The methods employed are similar to those used for bis-(aminophenyl) sulfones. The sulfides from 2-chloro-5-nitropyridine, 5-chloro-8-nitroquinoline, and 8-chloro-5-nitro-quinoline are readily oxidized by chromic acid to the sulfones. The properties of the amino compounds are under investigation. Phenyl pyridyl and quinolyl sulfones are also known.[269c]



The preparation of a number of alkylpyridine sulfones has been outlined.[270] Their parachors are in agreement with the theory that the sulfur-oxygen bonds are semi-polar. The oxidation of 4-methylthiopyridine with potassium permanganate in 20% acetic acid produces the sulfone in an 80% yield.[271]

The action of sulfuryl chloride upon the magnesium derivative of indole gives what was believed to be bis-(β-indyl) sulfone. The α-methyl compound reacted similarly but pyrolle itself gave an unidentified product.[272]

A heterocyclic sulfone in which nitrogen and sulfur are both part of a ring may be mentioned here.[273] Compounds referred to as "sulfurylindigo" and "sulfurylisatin" are produced by oxidation of the benzothiazoline dioxide.



UNSATURATED SULFONES

The sulfone linkage enhances the activity of an adjacent olefin bond to a marked degree. In most respects the activation is comparable to that produced by the keto group in the same position.

Vinyl Sulfone. Bis-(β-chloroethyl) sulfone when heated with zinc dust or zinc oxide[274] in alcohol slowly loses hydrogen chloride with formation of vinyl β-chloroethyl sulfone and finally vinyl sulfone in good yield. The latter has also been obtained[275] in 80% yield by the action of triethylamine on bis-(β-chloroethyl) sulfone in benzene solution at ordinary temperatures and by the oxidation of vinyl sulfide with perbenzoic acid.[276] It is a liquid d^{20} 1.1790, b.p. 118–121°/20 mm. It does not react with chlorine or hydrogen chloride[275] but adds bromine, hydrogen bromide, and iodine readily. Unusual reactivity of the double bonds is apparent in the effects of a variety of neutral and basic reagents. These are summarized by the accompanying equations.

In a number of instances compounds obtained from vinyl sulfone have also been prepared from either vinyl β-chloroethyl sulfone or bis-(β-chloroethyl) sulfone. Equations for these reactions are included in the list.

$$(CH_2{=}CH)_2SO_2 + 2NaHSO_3 \rightarrow (NaO_3SCH_2CH_2)_2SO_2 \quad (100\%\ \text{yield})$$

$$CH_2{=}CHSO_2CH_2CH_2Cl + 2NaHSO_3 \rightarrow (NaO_3SCH_2CH_2)_2SO_2 + HCl$$

$$(CH_2{=}CH)_2SO_2 + 2H_2O \rightarrow (HOCH_2CH_2)_2SO_2 \quad (100\%\ \text{yield})$$

$$(CH_2{=}CH)_2SO_2 + H_2O \xrightarrow{NaOH} O(CH_2CH_2)_2SO_2$$

$$CH_2{=}CHSO_2CH_2CH_2Cl + KOH \xrightarrow{H_2O} O(CH_2CH_2)_2SO_2 + KCl$$

$$(CH_2{=}CH)_2SO_2 + 2C_2H_5OH \xrightarrow{C_2H_5ONa} (C_2H_5OCH_2CH_2)_2SO_2$$

$$(ClCH_2CH_2)_2SO_2 + 2C_2H_5ONa \rightarrow (C_2H_5OCH_2CH_2)_2SO_2 + 2NaCl$$

$$(CH_2{=}CH)_2SO_2 + 2C_6H_5SH \rightarrow (C_6H_5SCH_2CH_2)_2SO_2$$

$$(ClCH_2CH_2)_2SO_2 + 2C_6H_5SNa \rightarrow (C_6H_5SCH_2CH_2)_2SO_2 + 2NaCl$$

$$ClCH_2CH_2SCH{=}CH_2 + 2C_2H_5SH + NaOH \rightarrow (C_2H_5SCH_2CH_2)_2SO_2 + NaCl$$

$$(CH{=}CH_2)_2SO_2 + 2C_6H_5OH \rightarrow (C_6H_5OCH_2CH_2)_2SO_2$$

$$(ClCH_2CH_2)_2SO_2 + 2C_6H_5ONa \rightarrow (C_6H_5OCH_2CH_2)_2SO_2 + 2NaCl$$

$$(CH_2{=}CH)_2SO_2 + 2C_6H_5NH_2 \rightarrow (C_6H_5NHCH_2CH_2)_2SO_2$$

$$(CH_2{=}CH)_2SO_2 + H_2NCH_2COOC_2H_5 \rightarrow C_2H_5OOCCH_2N(CH_2CH_2)_2SO_2$$

$$(CH_2{=}CH)_2SO_2 + C_6H_5NHNH_2 \rightarrow C_6H_5NHN(CH_2CH_2)_2SO_2$$

$$(CH_2{=}CH)_2SO_2 + H_2S \rightarrow S(CH_2CH_2)_2SO_2 \quad \text{(low yield)}$$

It was found that no reaction occurred with ammonia, hydrazine, formic acid, benzaldehyde, or phthalimide. It was suggested that in the reaction of basic reagents with bis-(β-chloroethyl) sulfone the first step in the reaction may be formation of an unsaturated compound.

Halogenated Vinyl Sulfones. α-Chlorovinyl β-chloroethyl sulfone and similar compounds have been prepared from the corresponding sulfides by oxidation with benzoyl peroxide.[277] The intermediate sulfoxide was easily isolated if the proper amount of oxidizing agent was used. A trace of bis-(β-chlorovinyl) sulfone has been obtained from the permanganate oxidation of bis-(α,β-dichloroethyl) sulfide.[278]

Aryl and Alkyl Vinyl Sulfones. The preparation of numerous sulfones of the general formula $RSO_2CH{=}CH_2$ (where R is practically any group that is not easily oxidized) by oxidation of the corresponding sulfides has been described in the patent literature.[279] Rothstein [280] prepared benzyl propenyl sulfone by the following series of changes.

$$C_6H_5CH_2SNa + ClCH_2CHOHCH_3 \rightarrow C_6H_5CH_2SCH_2CHOHCH_3 \xrightarrow{H_2O_2} C_6H_5CH_2SO_2CH_2CHOHCH_3 \xrightarrow{PCl_5} C_6H_5CH_2SO_2CH_2CHClCH_3 \xrightarrow{C_5H_5N} C_6H_5CH_2SO_2CH{=}CHCH_3$$

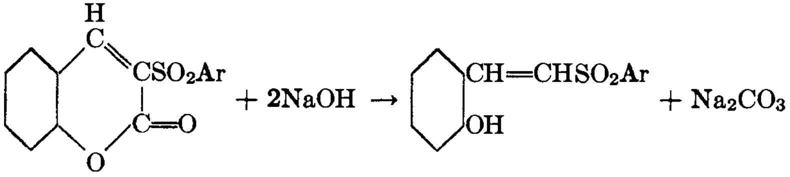
A convenient method of synthesizing β-phenylvinyl p-tolyl sulfone and similar compounds consists of adding p-thiocresol to phenylacetylene and oxidizing the resulting sulfide with hydrogen peroxide.[281]

$$C_6H_5C{\equiv}CH + p\text{-}C_7H_7SH \rightarrow C_6H_5CH{=}CHSC_7H_7\text{-}p \xrightarrow{H_2O_2} C_6H_5CH{=}CHSO_2C_7H_7\text{-}p$$

β-Phenylvinyl 2,4-dinitrophenylsulfone has been prepared by the reaction shown in the equation.[282]

$$2,4\text{-}(NO_2)_2C_6H_3Cl + C_6H_5CH{=}CHSO_2Na \rightarrow 2,4\text{-}(NO_2)_2C_6H_3SO_2CH{=}CHC_6H_5 + NaCl$$

Numerous β-(o-hydroxyaryl)-vinyl aryl sulfones have been obtained by the hydrolysis of arylsulfonylpyrones.[283]



Benzyl propenyl sulfone adds water or methanol in the presence of a small amount of alkali.[280] Boiling the sulfone with potassium hydroxide solution brings about a retrogressive aldol reaction. Ozonization gives benzoic acid.

$$C_6H_5CH_2SO_2CH{=}CHCH_3 \xrightarrow{H_2O} C_6H_5SO_2CH_3 + (CH_3CHO)_x$$

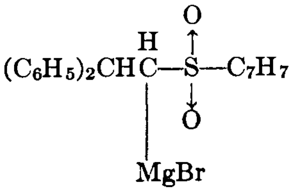
The olefin linkage in β-phenylvinyl *p*-tolyl sulfone[281] reacts normally with hydrogen, bromine, potassium permanganate solution, and ozone. *p*-Thiocresol, ethyl malonate, and phenylmagnesium bromide add as they do to the corresponding ketone. There is a yellow addition product formed as the first stage in this last reaction just as there

$$C_6H_5CH{=}CHSO_2C_7H_7 + C_7H_7SH \xrightarrow{NaOH} C_6H_5CH(SC_7H_7)CH_2SO_2C_7H_7$$

$$C_6H_5CH{=}CHSO_2C_7H_7 + CH_2(COOC_2H_5)_2 \xrightarrow{NaOC_2H_5} C_6H_5CH[CH(COOC_2H_5)_2]CH_2SO_2C_7H_7$$

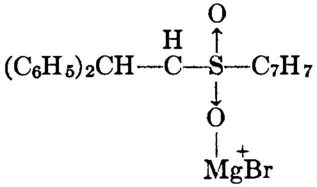
$$C_6H_5CH{=}CHSO_2C_7H_7 + C_6H_5MgBr \rightarrow [(C_6H_5)_2CHCHSO_2C_7H_7]MgBr$$

is in the analogous reaction with an unsaturated ketone. This goes over to a colorless final product which upon hydrolysis yields the β,β-diphenylethyl *p*-tolyl sulfone. Possible structures for the intermediate products are indicated by the formulas.



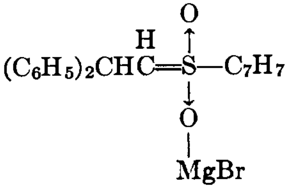
$$(C_6H_5)_2CH\overset{H}{\underset{\underset{MgBr}{|}}{C}}-\overset{\overset{O}{\uparrow}}{\underset{\underset{O}{\downarrow}}{S}}-C_7H_7$$

I



$$(C_6H_5)_2CH-\overset{H}{C}-\overset{\overset{O}{\uparrow}}{\underset{\underset{\underset{\overset{+}{MgBr}}{|}}{\overset{O}{\downarrow}}}{S}}-C_7H_7$$

II



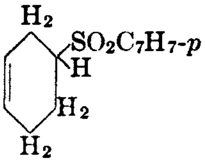
$$(C_6H_5)_2CH\overset{H}{C}{=}\overset{\overset{O}{\uparrow}}{\underset{\underset{\underset{MgBr}{|}}{\overset{O}{\downarrow}}}{S}}-C_7H_7$$

III

Structure III involves the presence of a ten-electron shell for the sulfur.

Several addition reactions of alkyl and aryl vinyl sulfones have been described in the patent literature including the addition of sodium bisulfite,[284] thiols, or hydrogen sulfide,[285] sulfinic acids,[286] and ammonia or amines.[287] Equations for these reactions except for the one with ammonia have already been written for vinyl sulfone [276] in a preceding section. *p*-Tolyl vinyl sulfone has been found to undergo the Diels-Alder reaction with butadiene.[288]

$$p\text{-}C_7H_7SO_2CH{=}CH_2 + C_4H_6 \rightarrow$$



Allyl Sulfones. An allyl halide reacts rapidly with an alkali sulfinate to yield the unsaturated sulfone. Compounds of this type are listed in Table XXX.

TABLE XXX

SULFINATE	ALLYL HALIDE AND REF.	M.P. OF SULFONE, °C.
$C_6H_5SO_2Na$	C_3H_5Br [1, 2]	Oil
$o\text{-}CH_3C_6H_4SO_2Na$	C_3H_5Br [8]	Oil
$p\text{-}CH_3C_6H_4SO_2Na$	C_3H_5Cl [1]	52–53
$2,4\text{-}(CH_3)_2C_6H_3SO_2Na$	C_3H_5I [3, 4]	52
$\alpha\text{-}C_{10}H_7SO_2Na$	C_3H_5Br [5]	67
$\beta\text{-}C_{10}H_7SO_2Na$	C_3H_5Br [5]	95
$C_6H_5CH_2SO_2Na$	C_3H_5Br [6]	Oil
$(CH_3SO_2)_2Mg$	C_3H_5Br [6]	B.p. 130/15 mm.
$C_6H_4(SO_2K)_2$	C_3H_5I [7]	105

[1] Otto, *Ann.*, **283**, 184 (1894).
[2] Tröger and Hinze, *J. prakt. Chem.*, [2] **55**, 202 (1897).
[3] Tröger and Budde, *ibid.*, [2] **66**, 130 (1902).
[4] Tröger and Hille, *ibid.*, [2] **68**, 310 (1903).
[5] Tröger and Artmann, *ibid.*, [2] **53**, 484 (1896).
[6] Rothstein, *J. Chem. Soc.*, 684 (1934).
[7] Tröger and Meine, *J. prakt. Chem.*, [2] **68**, 320 (1903).
[8] Tröger and Voigtlander-Tetzner, *ibid.*, [2] **64**, 513 (1896).

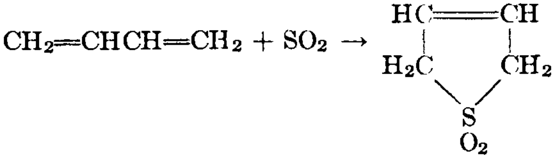
Phenyl allyl sulfone is reduced by zinc and hydrochloric acid to thiophenol. Boiling with alcoholic potassium hydroxide yields allyl alcohol and potassium benzenesulfinate.[289a] In contrast with this, benzyl allyl sulfone with 0.1 *N* potassium hydroxide adds a molecule of water while with 3 *N* alkali benzyl methyl sulfone results.[98]

$$C_6H_5CH_2SO_2CH_2CH{=}CH_2 + H_2O \xrightarrow{KOH} C_6H_5CH_2SO_2CH_2CHOHCH_3$$

$$C_6H_5CH_2SO_2CH_2CHOHCH_3 \xrightarrow{KOH} C_6H_5CH_2SO_2CH_3 + (CH_3CHO)_x$$

Bromine adds normally to phenyl allyl sulfone with formation of a dibromide, m.p. 80°. The dichloride has also been prepared.[289b] Halogen acids add in acetic acid solution to give β-halopropyl phenyl sulfones. The other aryl allyl sulfones listed in Table XXX react with halogens and halogen acids in precisely the same manner.

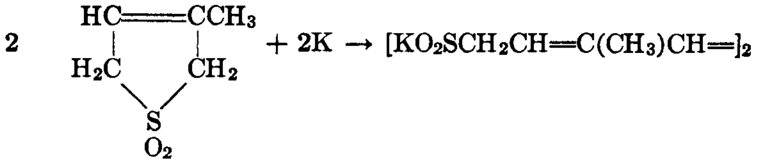
Unsaturated Cyclic Sulfones. Butadiene and many of its homologs react with sulfur dioxide to give amorphous polymeric substances and monomeric cyclic olefinic sulfones.[290] It is with the cyclic compounds that this section deals. The reaction has been effected under various conditions including the use of saturated aqueous ammonium sulfite [290e] at 120°, water saturated with sulfur dioxide at room temperature,[290c] an ether solution of sulfur dioxide [290b,e] at 100°, and liquid sulfur dioxide.[290j] From heating 10 g. of isoprene in 100 ml. of ether saturated with sulfur dioxide for 5 hours at 100° there results a 60% yield of isoprene sulfone.[290b] 2,4-Hexadiene, *trans, trans*-1,4-diphenyl-1,3-butadiene and *cis, cis*-1,4-dicarboxy-1,3-butadiene do not react,[290m] but 1,3-di-*tert*-butyl-1,3-butadiene does.

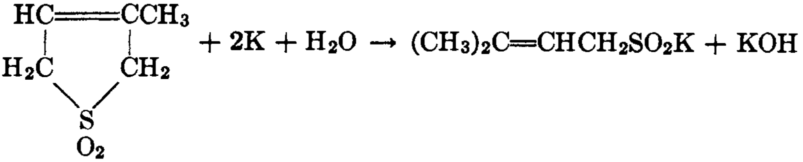


The crystal structures of several butadiene sulfones have been examined in detail.[291a] The solutions of the sulfones in nitric or sulfuric acid are highly viscous but precipitation with water gives the original sulfone unchanged.

3,4-Di-*p*-tolylthiophene is oxidized by perbenzoic acid to the sulfone.[291b] Reduction then occurs in the 1,4-positions.

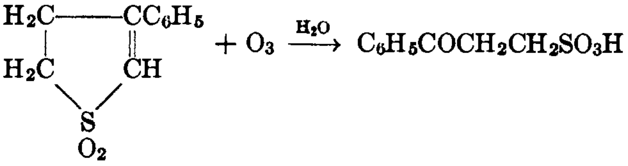
The information available concerning the reactions of the cyclic olefinic sulfones is unusually large and can be given only briefly. The oxidation of butadiene sulfone with peracetic acid in glacial acetic acid is slow [292] and erratic. Numerous addition reactions such as those with alcohols, amines, and phenols occur readily in alkaline solution.[293a] The α-unsaturated sulfone [288] undergoes the Diels-Alder reaction. Upon heating isoprene sulfone to 120–135° decomposition ensues with regeneration of some of the original isoprene. Boiling with 0.5 *N* sodium hydroxide has no effect. In titration with potassium permanganate in neutral solution nearly four atoms of oxygen react rapidly with formation of a monobasic acid. A side reaction in which sulfuric acid appears also takes place. Treatment of a dry ether solution of the sulfone with potassium metal yields an unstable sulfinic acid [290c] which polymerizes readily. With moist ether a monomeric compound is obtained.



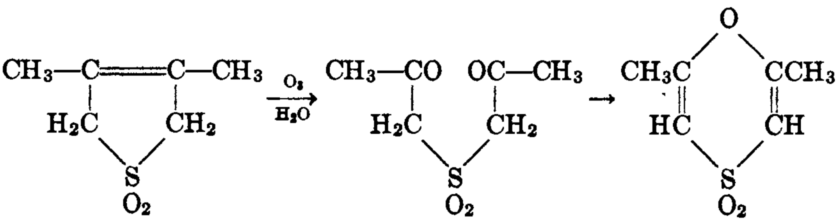


Hydrogenation can be effected by the use of a nickel and silicic acid catalyst in the presence of benzene.[293b]

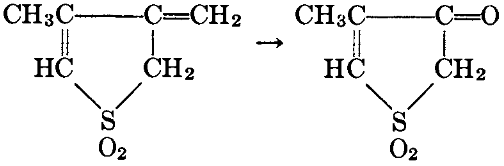
When isoprene sulfone is in contact with 0.5 *N* potassium hydroxide, ultraviolet light isomerizes it into a compound of m.p. 79°. Both sulfones reduce to the same saturated sulfone.[290d] It was suggested that these are *cis-trans* isomers but this is highly improbable[290m] because of the strained condition of the molecule it would necessitate. A more reasonable explanation which also accounts for the third isomer reported later[290g] is that the position of the double bond is involved. Strong evidence for this theory was obtained from a study of the isomeric sulfones from 2-phenyl-1,3-butadiene.[290i] The isomerized sulfone reacts as indicated.



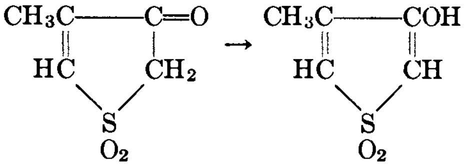
The sulfone from 2,3-dimethyl-1,3-butadiene has been carefully studied.[290f,n] Hydrolysis of the dibromide gives the *trans* glycol while by oxidation of the unsaturated sulfone the *cis* isomer is obtained. This with lead tetra-acetate[290h] gives diacetonyl sulfone, also synthesized by oxidation of the sulfide. Ozonization of the unsaturated sulfone also gives diacetonyl sulfone or a cyclic ether derived from it.



Splitting out hydrogen bromide from the dibromide does not give a thiophene sulfone as oxidation yields a ketone in which the ring is still intact. The yellow color appearing when the ketosulfone is treated with alkali may indicate that a thiophene derivative is



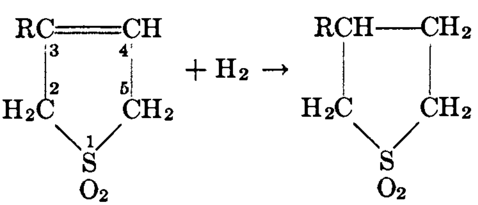
formed[290i] by enolization. The doubly unsaturated compound would not be aromatic in character as the sulfur atom electrons are not free



to assist in stabilizing the ring. It may be mentioned here that thiophene sulfones are known; examples are those obtained by the oxidation of tetraphenylthiophene (thionessal) and 3,4-diphenylthiophene with hydrogen peroxide.[294] Unlike most sulfones they are reduced by hydrochloric acid and zinc in acetic acid solution but not with the zinc and acetic acid alone.

Ozonization of the sulfone from 1,2,3,4-tetramethyl-1,3-butadiene gives bis-(α-methylacetonyl) sulfone. The sulfones from 2-phenyl- and 2-*tert*-butylbutadiene oxidize to keto acids.[290i]

A number of the unsaturated sulfones have been converted into the thiacyclopentane dioxides by catalytic reduction.[290l]



Reduction of 3-methyl-4-methylenethiacyclo-2-pentene-1,1-dioxide occurred much more rapidly than for the 3,4-dimethylthiacyclo-3-pentene, hence the first stage is not addition of hydrogen to the ends of the conjugated system. The double bond in the 3-position is more stable than that in the 2-position adjacent to the sulfone group.

Unsaturated Sulfonyl Acids. The isomeric β-phenylsulfonylcrotonic acids have been prepared by reaction of β-chlorocrotonic and β-chloroisocrotonic acids with sodium benzenesulfinate.[295] The sulfone from the chlorocrotonic acid may be converted into an isomer by heating the sodium salt to 200–210°. Cold potassium hydroxide solution reacts with ethyl β,β-diphenylsulfonylbutyrate to give this same sulfone.

$$CH_3CCl{=}CHCOONa + C_6H_5SO_2Na \xrightarrow[180^\circ]{160^\circ\text{-}} CH_3C(SO_2C_6H_5){=}CH{-}COOH + NaCl$$

$$CH_3C(SO_2C_6H_5)_2CH_2COOC_2H_5 + 2KOH \rightarrow CH_3C(SO_2C_6H_5){=}CHCOOK + H_2O + C_2H_5OH + C_6H_5SO_2K$$

These unsaturated sulfones are reduced by tin and hydrochloric acid to thiophenol. Bromine does not add to the double bond.

Sodium hydroxide decomposes propane-1,2-bis-(sulfonylacetic acid) to give an unsaturated sulfone.[296]

$$CH_3CH(SO_2CH_2COONa)CH_2SO_2CH_2COONa + NaOH \rightarrow CH_3CH{=}CHSO_2CH_2COONa + NaO_2SCH_2COONa + H_2O$$

With bromine water this undergoes an unusual degradation yielding bis-(tribromomethyl) sulfone.

$$CH_3CH{=}CH_2SO_2CH_2COOH + 6Br_2 + H_2O \rightarrow (CBr_3)_2SO_2 + CO_2 + [CH_3CHO] + 6HBr$$

Although the loss of the carboxyl group is to be expected because of the instability of brominated sulfone acids, the loss of two carbons from the propenyl chain in acid solution is unexpected.

Unsaturated Ketosulfones. Kohler and Larsen[297] have compared the properties of α-phenylsulfonyl-β-benzoylethylene with those of the corresponding diketone. The sulfone results from the reaction of sodium benzenesulfinate with β,β-dibromopropiophenone in alcoholic potassium acetate, but a more convenient method involves the following steps.

$$C_6H_5COCH_2CHBr_2 + C_6H_5SO_2Na + CH_3COOK \rightarrow C_6H_5COCH{=}CHSO_2C_6H_5 + NaBr + KBr + CH_3COOH$$

$$C_6H_5COCH_2CH_2Cl + C_6H_5SO_2Na \rightarrow C_6H_5COCH_2CH_2SO_2C_6H_5 + NaCl$$

$$C_6H_5COCH_2CH_2SO_2C_6H_5 + Br_2 \rightarrow C_6H_5COCHBrCH_2SO_2C_6H_5 + HBr$$

$$C_6H_5COCHBrCH_2SO_2C_6H_5 + CH_3COOK \rightarrow C_6H_5COCH{=}CHSO_2C_6H_5 + KBr + CH_3COOH$$

The yield for the first reaction was 68% and was over 90% for each of the last two. The saturated sulfone also may be obtained from benzenesulfinic acid and phenyl vinyl ketone. The structure of the

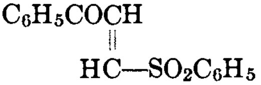
$$C_6H_5SO_2H + C_6H_5COCH{=}CH_2 \rightarrow C_6H_5COCH_2CH_2SO_2C_6H_5$$

bromination product was demonstrated by an independent synthesis.

$$C_6H_5COCHBrCH_2Br + C_6H_5SO_2Na \rightarrow C_6H_5COCHBrCH_2SO_2C_6H_5 + NaBr$$

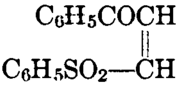
The yield of bromoketosulfone was 5% by this method.

The yellow unsaturated ketosulfone obtained in the preparation given above isomerizes when exposed to sunlight for 4 hours into a colorless isomer. By analogy with the diketones the two compounds have the following structures. The *cis* compound reverts to the *trans* isomer upon treatment with sodium methoxide in methanol or hydrogen chloride in acetic acid.



$$\begin{array}{l} C_6H_5COCH \\ \quad\;\; \| \\ \quad\;\; HC{-}SO_2C_6H_5 \end{array}$$

yellow, m.p. 114°



$$\begin{array}{r} C_6H_5COCH \\ \| \quad \\ C_6H_5SO_2{-}CH \end{array}$$

colorless, m.p. 149°

Reduction of the *cis* ketosulfone with zinc in dilute acetic acid or zinc amalgam in alcohol saturates the olefin bond. With bromine a mixture of dibromides is formed which upon treatment with potassium acetate gives α-phenylsulfonyl-β-bromo-β-benzoylethylene. The yellow product isomerizes readily in sunlight to the colorless *cis* isomer. Addition of hydrogen bromide to α-phenylsulfonyl-β-benzoylethylene gives a different compound than is obtained by brominating the saturated ketosulfone.

$$C_6H_5COCH{=}CHSO_2C_6H_5 + HBr \rightarrow C_6H_5COCH_2CHBrSO_2C_6H_5$$

By dissolving the ketosulfone in methyl alcoholic potassium hydroxide, adding ice and acidifying, two products are obtained.

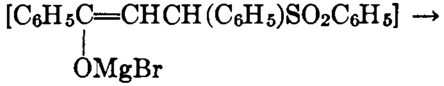
$$C_6H_5COCH{=}CHSO_2C_6H_5 + H_2O \rightarrow C_6H_5COCH_2CHOHSO_2C_6H_5$$

$$C_6H_5COCH_2CHOHSO_2C_6H_5 \rightarrow C_6H_5COCH_2CHO + C_6H_5SO_2H$$

The hydroxysulfone, an analog of a bisulfite addition product of an aldehyde, is readily decomposed by acids but forms a stable sodium salt with sodium bicarbonate.

Phenylmagnesium bromide adds to the ketosulfone as it does to other unsaturated ketones, but this reaction is followed by several others. The structure of the unsaturated tertiary alcohol was proved by reduction and synthesis of the saturated compound.

$$C_6H_5COCH{=}CHSO_2C_6H_5 + C_6H_5MgBr \rightarrow$$



$$[C_6H_5\underset{\displaystyle OMgBr}{\underset{|}{C}}{=}CHCH(C_6H_5)SO_2C_6H_5] \rightarrow$$

$$C_6H_5COCH{=}CHC_6H_5 + C_6H_5SO_2MgBr$$

$$C_6H_5COCH{=}CHSO_2C_6H_5 + C_6H_5MgBr \rightarrow$$

$$(C_6H_5)_2C(OMgBr)CH{=}CHSO_2C_6H_5 \rightarrow$$

$$(C_6H_5)_2COHCH{=}CHSO_2C_6H_5 \rightleftharpoons (C_6H_5)_2C{=}CHCHOHSO_2C_6H_5$$

$$C_6H_5SO_2MgBr + C_6H_5MgBr \rightarrow (C_6H_5)_2SO + O(MgBr)_2$$

$$C_6H_5COCH{=}CHC_6H_5 + C_6H_5MgBr \rightarrow$$

$$C_6H_5C(OMgBr){=}CHCH(C_6H_5)_2$$

$$(C_6H_5)_2COHCH{=}CHSO_2C_6H_5 + H_2 \xrightarrow{Pt}$$

$$(C_6H_5)_2COHCH_2CH_2SO_2C_6H_5$$

$$C_6H_5COCH_2CH_2SO_2C_6H_5 + C_6H_5MgBr \rightarrow$$

$$(C_6H_5)_2COHCH_2CH_2SO_2C_6H_5$$

Heating the secondary alcohol produced a small amount of the aldehyde, identified as the phenylhydrazone.

$$(C_6H_5)_2C{=}CHCHOHSO_2C_6H_5 \rightarrow (C_6H_5)_2C{=}CHCHO + C_6H_5SO_2H$$

DI-, TRI-, AND POLYSULFONES

α-Disulfones. The first α-disulfones were obtained by the action of a sulfonyl chloride with a sodium sulfinate.[298]

$$C_6H_5SO_2Na + p\text{-}CH_3C_6H_4SO_2Cl \rightarrow C_6H_5SO_2SO_2C_6H_4CH_3\text{-}p + NaCl$$

Formation of this same disulfone from benzenesulfonyl chloride and sodium *p*-toluenesulfinate confirms the assigned structure.[299] Oxidation of *p*-tolyl hydroxymethyl sulfone[300] (from formaldehyde and the sulfinic acid) or of a sulfinic acid[301] with potassium permanganate gives up to 40% yields of the corresponding disulfone.

$$6p\text{-}CH_3C_6H_4SO_2H + 2KMnO_4 \rightarrow$$

$$3(p\text{-}CH_3C_6H_4SO_2)_2 + 2MnO_2 + 2KOH + 2H_2O$$

The reaction is best carried out by adding powdered permanganate to a cold acetic acid solution of the sulfinic acid. One aliphatic disulfone, that from *d*-β-camphorsulfinic acid, has been prepared by this method.[302] The α-disulfones described in the preceding references [298-302] are listed in Table XXXI.

TABLE XXXI

Disulfone	M.P., °C.
$(C_6H_5SO_2)_2$	193–194
$(p\text{-}CH_3C_6H_4SO_2)_2$	221 (210–212) (decomp.)
$[2,5\text{-}(CH_3)_2C_6H_3SO_2]_2$	199
$(p\text{-}C_2H_5OC_6H_4SO_2)_2$	208 (decomp.)
$(d\text{-}\beta\text{-}C_{10}H_{15}O \cdot SO_2)_2$ (camphor deriv.)	138
$C_6H_5SO_2SO_2C_6H_4CH_3\text{-}p$	166
$C_6H_5SO_2SO_2C_{10}H_7\text{-}\beta$	166
$4,2\text{-}(NO_2)CH_3C_6H_3SO_2SO_2C_6H_4CH_3\text{-}p$	154

α-Disulfones are only slightly soluble in most solvents. They are unaffected by boiling with water, concentrated hydrochloric acid, or dilute alkali. With concentrated or alcoholic potassium hydroxide [298] cleavage occurs. Warming with concentrated ammonia also brings this about, although the products differ.[300,301] With phenylhydrazine

$$C_6H_5SO_2SO_2C_6H_5 + 2KOH \rightarrow C_6H_5SO_2K + C_6H_5SO_3K + H_2O$$

only the sulfinate was isolated. Boiling *p*-tolyl disulfone with con-

$$(p\text{-}CH_3C_6H_4SO_2)_2 + 2NH_3 \rightarrow$$
$$p\text{-}CH_3C_6H_4SO_2NH_2 + p\text{-}CH_3C_6H_4SO_2NH_4$$

centrated nitric acid gives a dinitro compound, not obtained in a pure condition, however.[301]

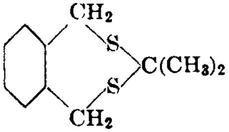
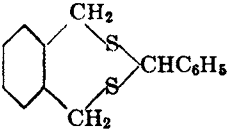
β-Disulfones: Preparation. Compounds containing two sulfone groups separated by a carbon atom have been found to be of interest in at least two ways. Hydrogens attached to the carbon are slightly acidic and undergo some of the reactions typical of methylene hydrogen. Sulfones containing two or more ethyl or higher alkyl groups have some value as hypnotics. Typical of these is sulfonal, $(CH_3)_2C(SO_2C_2H_5)_2$.

Preparation of the β-disulfones has most frequently been effected by oxidation of the disulfides. The yields are low for compounds containing large alkyl or phenyl groups. All attempts to oxidize bis-(*p*-nitrophenylthiol)-methane to the corresponding disulfone were unsuccessful, water-soluble sulfonic acids resulting. The results obtained by this method are summarized in Table XXXII.

TABLE XXXII

Sulfide Oxidized	Reagent and Reference	Reaction Data	M.P. of Disulfone, °C.
$(CH_3S)_2CH_2$	1% $KMnO_4$ [1,3]	Nearly 100% yield	142–143
$CH_3SCH_2SC_2H_5$	1% $KMnO_4$ [3]	High yield	94–95
$(C_2H_5S)_2CH_2$	1 or 5% $KMnO_4$ [2,3]	Acid sol., high yield	104
	H_2O_2 in AcOH [27]		
$(n\text{-}C_4H_9S)_2CH_2$	CrO_3 [4]	13% yield	95–96
$(\text{iso-}C_4H_9S)_2CH_2$	$KMnO_4$ [6]	Acid sol.	85
$(\text{iso-}C_5H_{11}S)_2CH_2$	$KMnO_4$ [6]	....	138–139
$(C_6H_5CH_2S)_2CH_2$	5% $KMnO_4$ [7]	Acid sol.	216
$C_6H_5CH_2SCH_2SC_2H_5$	$KMnO_4$ [6]	....	172–174
$C_6H_5SCH_2SCH_3$	1% $KMnO_4$ [3]	....	147
$C_6H_5SCH_2SC_2H_5$	1% $KMnO_4$ [3,6]	....	110–111
$C_6H_5SCH_2SC_5H_{11}\text{-iso}$	$KMnO_4$ [6]	....	86–88
$C_6H_5SCH_2SCH_2C_6H_5$	$KMnO_4$ [6]	....	145–147
$p\text{-}CH_3C_6H_4SCH_2SCH_3$	$KMnO_4$ [3]	....	158
$(C_6H_5S)_2CH_2$	$KMnO_4$ [2]	Acid sol.	120–121
	CrO_3 [11]	18% yield	....
$(CH_3S)_2CHCH_3$	$KMnO_4$ [1,3,13]	....	122
$(C_2H_5S)_2CHCH_3$	$KMnO_4$ [8,13]	Acid sol.	75
$(\text{iso-}C_5H_{11}S)_2CHCH_3$	$KMnO_4$ [6]	....	130
$(C_6H_5CH_2S)_2CHCH_3$	$KMnO_4$ [6,7]	....	130
$C_6H_5SCH(CH_3)SCH_3$	$KMnO_4$ [3]	....	104
$(C_6H_5S)_2CHCH_3$	$KMnO_4$ [9,10]	Acetic acid sol.	101–102
$C_6H_5SCH(CH_3)SCH_2C_6H_5$	$KMnO_4$ [6]	....	144
$(CH_3S)_2CHC_2H_5$	$KMnO_4$ [1]	....	97
$(C_2H_5S)_2CHC_2H_5$	$KMnO_4$ [1,2]	Acid sol.	77
$(\text{iso-}C_5H_{11}S)_2CHC_6H_5$	$KMnO_4$ [6]	....	99–100
$C_2H_5SCH(C_6H_5)SC_6H_5$	$KMnO_4$ [6]	....	155–156
$\text{iso-}C_5H_{11}SCH(C_6H_5)SC_6H_5$	$KMnO_4$ [6]	....	145
$C_6H_5CH_2SCH(C_6H_5)SC_6H_5$	$KMnO_4$ [6]	....	173–174
$(CH_3S)_2C(CH_3)_2$	5% $KMnO_4$ [1]	Neutral sol.	118
$(C_2H_5S)_2C(CH_3)_2$	5% $KMnO_4$ [1]	Neutral sol.	127–128
$(\text{iso-}C_4H_9S)_2C(CH_3)_2$	$KMnO_4$ [15]	Very small yield	64
$(\text{iso-}C_5H_{11}S)_2C(CH_3)_2$	$KMnO_4$ [16]	Very small yield	72
$(C_6H_5CH_2S)_2C(CH_3)_2$	$KMnO_4$ [6]	....	153
$(C_6H_5S)_2C(CH_3)_2$	$KMnO_4$ [16]	Dil. H_2SO_4	182
$(C_2H_5S)_2C(CH_3)CH_2Cl$	$KMnO_4$ [17]	Acid sol.	78–79
$(CH_3S)_2C(CH_3)C_2H_5$	5% $KMnO_4$ [1]	Neutral sol.	74
$(C_2H_5S)_2C(CH_3)C_2H_5$	$KMnO_4$ [1,2,18]	Neutral sol.	76
$(CH_3S)_2C(CH_3)CHClCH_3$	$KMnO_4$ [19]	....	70–71
$(C_2H_5S)_2C(CH_3)C_3H_7\text{-}n$	$KMnO_4$ [18]	Dil. H_2SO_4	86
$(CH_3S)_2C(C_2H_5)_2$	$KMnO_4$ [1]	Neutral sol.	132–133
$(C_2H_5S)_2C(C_2H_5)_2$	$KMnO_4$ [1,20,22]	Neutral sol.	85

TABLE XXXII (*Continued*)

SULFIDE OXIDIZED	REAGENT AND REFERENCE	REACTION DATA	M.P. OF DISULFONE, °C.
$(C_2H_5S)_2C(CH_3)C_4H_9$-*n*	$KMnO_4$ [21]	....	....
$(C_2H_5S)_2C(C_3H_7$-*n*$)_2$	$KMnO_4$ [12]	Poor yield	109.5
$(C_2H_5S)_2C(C_3H_7$-*n*$)C_3H_7$-iso	$KMnO_4$ [12]	Poor yield	91
$(C_2H_5S)_2C(C_3H_7$-iso$)_2$	$KMnO_4$ [15]	Poor yield	97
$(C_2H_5S)_2{=}C_6H_{10}$-*cyclo*	$KMnO_4$ [12]	Poor yield	121
$(C_2H_5S)_2C(CH_3)CH_2C_6H_5$	5% $KMnO_4$ [14]	28% yield	125.5
$(C_6H_5CH_2S)_2C(CH_3)COC_2H_5$	$KMnO_4$ [25]	Acid sol.	....
$(C_6H_5S)_2C(CH_3)_2$	$KMnO_4$ [16]	Acid sol.	182
$(C_6H_5S)_2C(CH_3)CH_2COOC_2H_5$	$KMnO_4$ [23]	Acid sol.	98–99
$(C_6H_5S)_2C(CH_3)CH_2CH_2COOH$	$KMnO_4$ [24]	Acetic acid sol.	140
$(C_6H_5S)_2C(CH_3)CH_2CH_2COOC_2H_5$	$KMnO_4$ [24]	Acetic acid sol.	112–113
$(C_6H_5S)_2C(CH_3)CH(CH_3)COOC_2H_5$	$KMnO_4$ [24]	....	130
$(C_6H_5S)_2C(CH_3)CH(C_2H_5)COOC_2H_5$	$KMnO_4$ [23]	Acid sol.	111
	5% $KMnO_4$ [26]	Acid sol.	>300
	5% $KMnO_4$ [26]	Acid sol.	>300

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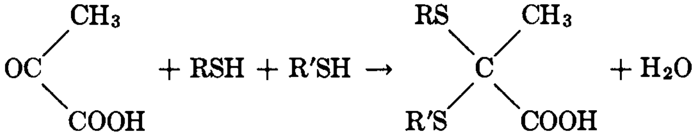
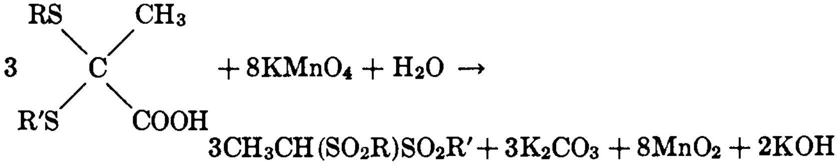
[1] Baumann and Kast, *Z. physiol. Chem.*, **14**, 55 (1890); Baumann, *Ber.*, **23**, 1875 (1890).
[2] Fromm, *Ann.*, **253**, 135 (1889).
[3] Gibson, *J. Chem. Soc.*, 2637 (1931).
[4] Stutz and Shriner, *J. Am. Chem. Soc.*, **55**, 1242 (1933).
[5] Stuffer, *Ber.*, **23**, 3231 (1890).
[6] Posner, *Ber.*, **35**, 296 (1903).
[7] Fromm, Forster, and Scherschewitski, *Ann.*, **394**, 344 (1912).
[8] Fromm, *Ann.*, **253**, 140 (1889).
[9] Escales and Baumann, *Ber.*, **19**, 2815 (1886).
[10] Otto and Mühle, *Ber.*, **28**, 1121 (1895).
[11] Shriner, Struck, and Jorison, *J. Am. Chem. Soc.*, **52**, 2060 (1930).
[12] Recsei, *Ber.*, **60B**, 1420 (1927).
[13] Ramberg and Samén, *C.A.*, **28**, 6103 (1934).
[14] Ogata and Ito, *J. Pharm. Soc. Japan*, No. 409,209 (1916); *C.A.*, **10**, 1646 (1916).
[15] Stuffer, *Ber.*, **23**, 3226 (1890).
[16] Baumann, *Ber.*, **19**, 2808 (1886).
[17] Autenrieth, *Ber.*, **24**, 171 (1891).
[18] Bayer and Co., German pat., 49,073, *Frdl.*, **2**, 521.
[19] Posner and Fahrenhorst, *Ber.*, **32**, 2755 (1899).
[20] Bayer and Co., German pat., 49,366, *Frdl.*, **2**, 523.
[21] Hildebrandt, *Arch. exp. Path. Pharmakol.*, **53**, 92 (1905).
[22] Schaum, Schaeling, and Klausing, *Ann.*, **411**, 192 (1916).
[23] Autenrieth, *Ann.*, **252**, 367 (1890).
[24] Posner, *Ber.*, **34**, 2652 (1901).
[25] Posner, *Ber.*, **35**, 499 (1902).
[26] Autenrieth and Hennings, *Ber.*, **34**, 1772 (1901).
[27] Böhme, *Ber.*, **69B**, 1610 (1936).

An ingenious method for preparing the sulfones with different alkyls attached to the two sulfur atoms is to condense pyruvic acid successively with different thiols and then oxidize the resulting product. The mixed disulfides from pyruvic acid are more easily obtained than are those of acetaldehyde. Upon oxidation the carboxyl group is lost.[303] Since the presence of even one sulfone group in the α-position facilitates loss of carbon dioxide from a carboxylic acid, the more pronounced effect of two such groups is understandable. The sulfones in Table XXXIII have been prepared by this pyruvic acid method.



$$OC(CH_3)(COOH) + RSH + R'SH \rightarrow (RS)(R'S)C(CH_3)(COOH) + H_2O$$



$$3\,(RS)(R'S)C(CH_3)(COOH) + 8KMnO_4 + H_2O \rightarrow 3CH_3CH(SO_2R)SO_2R' + 3K_2CO_3 + 8MnO_2 + 2KOH$$

TABLE XXXIII

Disulfone	M.P., °C.
$CH_3CH(SO_2C_2H_5)SO_2C_6H_5$	97–99
$CH_3CH(SO_2C_5H_{11})SO_2C_6H_5$	84–86
$CH_3CH(SO_2CH_2C_6H_5)SO_2C_6H_5$	144

Bis-(*p*-tolylsulfonyl)-methane has been prepared by hydrolysis of the corresponding acetamide derivative;[253] carbon dioxide is lost also in this reaction.

$$(p\text{-}C_7H_7SO_2)_2CHCONH_2 \xrightarrow{H_2O} (p\text{-}C_7H_7SO_2)_2CH_2 + NH_3 + CO_2$$

Oxidation of trithioörthoformates with permanganate in acid solution produces a disulfone as one of the reaction products. Thus ethyl trithioörthoformate yields bis-(ethylsulfonyl)-methane[304] and benzyl trithioörthoformate is converted into bis-(benzylsulfonyl)-methane.[305] Because of the side reactions which occur this is, however, hardly to be recommended as a general preparatory method.

Oxidation of the tetrasulfide, $CH_3C(SCH_2C_6H_5)_2CH_2C(SCH_2C_6H_5)_2CH_3$, with permanganate in dilute sulfuric acid gives a disulfone with loss of two sulfur atoms.[306]

$$[CH_3C(SCH_2C_6H_5)_2]_2CH_2 \xrightarrow{\text{oxid.}} CH_3C(SO_2CH_2C_6H_5)_2CH_2COCH_3$$

Since β-ketosulfones are convertible into β-sulfidosulfones (see p. 723) oxidation of the latter has been utilized to prepare β-disulfones. Hydrogen peroxide or potassium permanganate is a satisfactory reagent.[307]

α-Amino-β,β-bis-(phenylsulfonyl)-propane is obtained in small yield by hydrolysis of the phthalimido compound with hydrochloric acid[308] at 180–190°. The action of methylmagnesium iodide upon

$$(C_6H_5SO_2)_2C(CH_3)CH_2N(CO)_2C_6H_4 + H_2O \rightarrow (C_6H_5SO_2)_2C(CH_3)CH_2NH_2 + C_6H_4(COOH)_2$$

benzenesulfonyl fluoride[309] and the *p*-ethyl derivative give small yields (1–10%) of the corresponding bis-(arylsulfonyl)-methanes.

β-Disulfones: Reactions. In regard to their chemical behavior β-disulfones may be divided into two classes, depending upon the presence or absence of hydrogen on the carbon subtended by the sulfone groups. The former compounds undergo reactions with a number of reagents whereas the latter are unusually inert.

Bis-(ethylsulfonyl)-methane is readily alkylated[310] with methyl iodide and alcoholic alkali to mono and dimethyl derivatives.

$$(C_2H_5SO_2)_2CH_2 + 2CH_3I + 2KOH \rightarrow (C_2H_5SO_2)_2C(CH_3)_2 + 2KI + 2H_2O$$

Similar methylations have been carried out with bis-(*n*-butylsulfonyl)-methane,[311] bis-(phenylsulfonyl)-methane,[310,311b] phenylsulfonylbenzylsulfonylmethane,[303] bis-(benzylsulfonyl)-ethane,[312] α,α-bis-(ethylsulfonyl)-ethane,[310,313] bis-(ethylsulfonyl)-phenylmethane,[310] and α-ethylsulfonyl-α-phenylsulfonylethane.[310] This last compound[303] has also been ethylated with ethyl iodide as has α,α-bis-(ethylsulfonyl)-ethane.[310,313] *p*-Tolylsulfonyl-*p*-ethylcarboxyphenylsulfonylmethane has been benzylated.[307b] Attempted methylation of α,α,γ,γ-tetra(ethylsulfonyl)propane[314] yields sulfonal with loss of the methylene group, probably as formaldehyde. This is a reversal of the reaction obtained by long heating of the bis-(ethylsulfonyl)-methane with formaldehyde in neutral solution.

$$p\text{-}C_2H_5OOCC_6H_4SO_2CH_2SO_2C_6H_4CH_3\text{-}p + C_6H_5CH_2I + NaOC_2H_5 \rightarrow p\text{-}C_2H_5OOCC_6H_4SO_2CH(CH_2C_6H_5)SO_2C_6H_4CH_3\text{-}p + NaI + C_2H_5OH$$

Somewhat analogous to an alkylation reaction is the behavior of β-disulfones toward thiolsulfonates in alcoholic sodium ethoxide.[307] β-Disulfones do not react with benzenediazonium chloride or nitrous

$$CH_3SO_2CH_2SO_2C_2H_5 + C_6H_5SO_2SC_6H_5 + NaOC_2H_5 \rightarrow CH_3SO_2CH(SC_6H_5)SO_2C_2H_5 + C_6H_5SO_2Na + C_2H_5OH$$

acid. Of several aldehydes tried formaldehyde is the only one that reacts.[814]

The acidity of β-disulfones as evidenced by their alkylation and their solubility in aqueous alkali has caused considerable discussion. They are actually very weak acids, the ionization of bis-(ethylsulfonyl)-methane amounting to 0.1% in 1 N solution. It has been pointed out[311b] that in contrast to the β-diketones the acid properties cannot be due to enolization without assuming the existence of a ten electron shell for the sulfur atom and hence that the ionic charge is probably on the carbon atom. If this is correct it should be possible to prepare an optically active β-disulfone which does not racemize so readily as do the compounds where racemization proceeds through enolization. All attempts to obtain such a sulfone have so far been unsuccessful. Kipping[307b] found that the acid $p\text{-}CH_3C_6H_4SO_2CH(CH_2C_6H_5)SO_2C_6H_4COOH\text{-}p$ and other similar disulfones could not be resolved by any of the usual methods. Furthermore, although the sulfide-sulfone $CH_3C_6H_4SCH(CH_3)SO_2C_6H_4COOH$ could be resolved, it racemized readily and oxidation of either form gave the same inactive disulfone. Closely similar results were obtained with α-phenylsulfonyl-α-*p*-carboxyphenylsulfonylethane.[815] A disulfone with no hydrogen on the carbon between the two sulfone groups was, however, resolvable. This compound was obtained as indicated by the equations.

$$p\text{-}CH_3C_6H_4SO_2CH(CH_3)SO_2C_6H_4COOC_2H_5 + C_6H_5SO_2SC_6H_5 + C_2H_5ONa \rightarrow$$
$$p\text{-}CH_3C_6H_4SO_2C(CH_3)(SC_6H_5)SO_2C_6H_4COOC_2H_5 + C_6H_5SO_2Na + C_2H_5OH$$

$$p\text{-}CH_3C_6H_4SO_2C(CH_3)(SC_6H_5)SO_2C_6H_4COOC_2H_5 + NaOH \rightarrow$$
$$p\text{-}CH_3C_6H_4SO_2C(CH_3)(SC_6H_5)SO_2C_6H_4COONa + C_2H_5OH$$

It may be concluded from the results so far reported that an enolization of the β-disulfones is responsible for their solubility in alkali and their racemization; that the sulfur atom may exist, at least temporarily, in a pentacovalent state.

As is implied by the foregoing, β-disulfones do not undergo cleavage with alkali as do the γ-compounds taken up later. It has been observed, however, that ethyl β,β-diphenylsulfonylbutyrate[816] loses one sulfone group when treated with cold concentrated alkali.

$$(C_6H_5SO_2)_2C(CH_3)CH_2COOC_2H_5 + 2KOH \rightarrow$$
$$C_6H_5SO_2C(CH_3){=}CHCOOK + C_6H_5SO_2K + C_2H_5OH + H_2O$$

It is evident that the carboxyl group has an activating effect.

The methylene hydrogen of β-disulfones is readily replaceable by halogen. Aqueous chlorine or bromine, or iodine in potassium iodide reacts with bis-(ethylsulfonyl)-methane[310,317] to give the dihalogenated product. Bis-(methylsulfonyl)-methane has been dichlorinated and α,α-bis-(methylsulfonyl)-ethane has been iodinated in similar fashion.[307a] In a bromination of α,α-bis-(ethylsulfonyl)-ethane it was noted[318] that sunlight markedly accelerates the reaction. A study of the kinetics of the bromination in aqueous solution[319] showed the reaction to be bimolecular even when bromine is present in excess, indicating that enolization of the sulfone is not an intermediate step as it is with ketones.

Chlorination of bis-(ethylsulfonyl)-methane[307a] and α,α-bis-(ethylsulfonyl)-ethane[314] has been effected by treatment with benzenesulfonyl chloride. Whether or not a second halogen can be introduced in this manner has not been reported.

$$CH_3CH(SO_2C_2H_5)_2 + C_6H_5SO_2Cl + NaOC_2H_5 \rightarrow$$
$$CH_3CCl(SO_2C_2H_5)_2 + C_6H_5SO_2Na + C_2H_5OH$$

The reactions of these halogenated disulfones are of considerable interest. Bis-(*n*-butylsulfonyl)-dibromomethane with aqueous potassium iodide liberates iodine.[311] Boiling bis-(ethylsulfonyl)-dibromomethane or α,α-bis-(ethylsulfonyl)-α-bromoethane in part regenerates the sulfone, sulfuric acid and a sulfonic acid being the oxidation products. No keto or hydroxy compound was isolated. α,α-Bis-(ethylsulfonyl)-α-bromoethane[310] reacts with ethanethiol or thiophenol in alkaline solution to give the disulfide. With aniline colored unidentified oxidation products were found. Aqueous ammonia, sodium acetate, and potassium thiocyanate all replace the bromine with hydrogen. Bis-(ethylsulfonyl)-diiodomethane reacts with ethyl sodiomalonate[320] as follows.

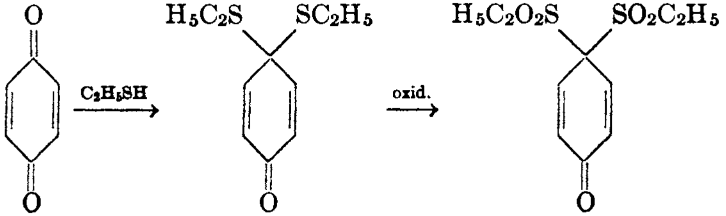
$$(C_4H_9SO_2)_2CBr_2 + 4KI + 2H_2O \rightarrow$$
$$(C_4H_9SO_2)_2CH_2 + 2I_2 + 2KBr + 2KOH$$

$$(C_2H_5SO_2)_2CI_2 + 2NaCH(COOC_2H_5)_2 \rightarrow$$
$$(C_2H_5SO_2)_2CH_2 + [{=}C(COOC_2H_5)]_2 + 2NaI$$

As mentioned earlier, the completely alkylated sulfones are chemically unreactive. No change occurs upon boiling with alkali or dissolving in concentrated sulfuric acid[321] and no reaction occurs with the halogens. Certain of these compounds are, however, of some value as hypnotics. β,β-Bis-(methylsulfonyl)-propane is inactive but replacing the methyls by ethyl groups gives compounds of increasing physiological potency.[322] Ethyl sulfone has no effect even in large doses and bis-(methylsulfonyl)-methane, bis-(ethylsulfonyl)-methane, α,α-bis-(ethylsulfonyl)-ethane, α,α-bis-(ethylsulfonyl)-propane, and ω,ω-bis-(ethylsulfonyl)-toluene are either inactive or produce undesirable physiological effects along with their hypnotic action. If the hypnotic effect of sulfonal, $(C_2H_5SO_2)_2C(CH_3)_2$, is given the value of unity, that of tetronal, $(C_2H_5)_2C(SO_2C_2H_5)_2$, is ten and of δ,δ-bis-(ethylsulfonyl)-heptane is twenty-five.[321] The disulfone from cyclohexanone, $C_6H_{10}(SO_2C_2H_5)_2$, is equal in effect to tetronal.

Small amounts of sulfonal may be detected either by fusion with potassium hydroxide and noting the color changes upon cooling and dissolving in water or by reduction with sodium and applying the nitroprusside test for the thiol group[323] to the reaction product. Sulfonal and the more highly ethylated compounds are partly unchanged in the body and are partly oxidized to ethanesulfonic acid. Fuchs[324] has given a review of the usefulness of sulfonal and others of the earlier-known hypnotics.

Quinonedisulfones. An interesting class of β-disulfones is that obtained by oxidizing the condensation products of quinones and thiols.[325] The dark violet benzoquinone disulfone, m.p. 84°, is easily reduced to



a colorless oil which is reoxidized by the oxygen of the air. The remaining keto group of the quinone does not react with hydroxylamine, semi-carbazide or phenylhydrazine except that the last-named substance causes reduction. Bromine reacts readily to give a tetrabromoquinone which then adds four more atoms of bromine at 100°. 1,4-Naphthoquinone has also been used in preparing a disulfone.

γ-Disulfones: Preparation. Attempts to prepare β-disulfones by reaction of a methylene halide with an alkali sulfinate[326] have been unsuccessful but when the halogens are not attached to the same carbon atom, reaction generally occurs in a satisfactory manner.

Below are listed the disulfones derived from ethylene bromide by boiling with a sulfinate in alcohol. Attempts to obtain a disulfone by heating sodium ethanesulfinate with propylene bromide have been unsuccessful but after four days' boiling of an alcohol solution of propylene bromide and sodium benzenesulfinate[327] some of the disulfone was obtained. Similar results were reported for sodium *p*-toluenesulfinate with propylene bromide and sodium benzenesulfinate with β-butylene bromide and with isobutylene bromide.

TABLE XXXIV

SULFONES FROM ETHYLENE BROMIDE

Sulfinate and Reference	Disulfone, M.P., °C.
$C_2H_5SO_2Na$ [1]	136.5
$C_6H_5SO_2Na$ [2, 3]	179.5–180
p-$ClC_6H_4SO_2Na$ [4, 7]	255, 237–238
p-$BrC_6H_4SO_2Na$ [4]	261
m-$O_2NC_6H_4SO_2Na$ [5]	226
p-$CH_3C_6H_4SO_2Na$ [6]	200–201

[1] Otto, *J. prakt. Chem.*, [2] **36**, 437 (1887).
[2] Otto, *Ber.*, **13**, 1280 (1880).
[3] Otto, *J. prakt. Chem.*, [2] **30**, 174 (1884).
[4] Tröger and Budde, *ibid.*, [2] **66**, 139 (1902).
[5] Limpricht, *Ann.*, **294**, 244 (1897).
[6] Otto, *J. prakt. Chem.*, [2] **30**, 354 (1884).
[7] Purgotti, *C.A.*, **13**, 2515 (1919).

Heating 1,1,1-trichloroethane with sodium benzenesulfinate in alcohol at 130–140° for 8 hours unexpectedly yields α,β-bis-(phenylsulfonyl)-ethane as the chief product.[328] This disulfone also results from

$$CH_3CCl_3 + 3C_6H_5SO_2Na + H_2O \rightarrow (CH_2SO_2C_6H_5)_2 + 3NaCl + C_6H_5SO_3H$$

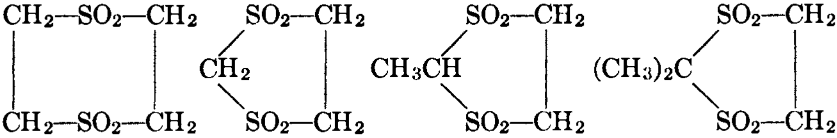
1,1,2-trichloroethane[329] or sodium α,α-dichloropropionate.[330]

$$CH_3CCl_2COONa + 2C_6H_5SO_2Na + H_2O \rightarrow (CH_2SO_2C_6H_5)_2 + NaHCO_3 + 2NaCl$$

Sulfones have been obtained without difficulty by the action of sodium 1,2-ethanedisulfinate with methyl, ethyl, and *n*-propyl bromides.[331]

$$(CH_2SO_2Na)_2 + 2C_2H_5Br \rightarrow (CH_2SO_2C_2H_5)_2 + 2NaBr$$

Several γ-disulfones have been obtained by oxidation of the corresponding disulfides. This reaction has its limitations, however, for although α,β-bis-(ethylsulfonyl)-ethane[332] and α,β-bis-(phenylsulfonyl)-propane[333] have been prepared by oxidation of the sulfides with potassium permanganate, an attempt to prepare α,β-bis-(ethylsulfonyl)-propane in this manner was unsuccessful. In this instance the disulfide was not isolated in a pure state, however, and this may have been responsible for the disulfone not being obtained. α,β-Bis-(phenylsulfonyl)-ethane has also been prepared by oxidizing the sulfide with chromic acid[334] and by oxidizing α,α,β-tris-(phenylthiol)-ethane with 3% potassium permanganate in acid solution.[329] The oxidation of α.β-bis-(*p*-nitrophenylthiol)-ethane with chromic acid in glacial acetic acid gives the sulfone in 75% yield.[186a] α,β-Propylene bis-(sulfonylacetic acid) and many similar compounds have been obtained in satisfactory yield by permanganate oxidation of the disulfide.[335] This reagent is also useful in the preparation of cyclic disulfones[336] such as those shown.



When α,β-di-*p*-tolyl ethylene disulfide is treated with a nitrating mixture[337] there is obtained first a dinitro and then a tetranitro disulfone. The unsubstituted disulfone was prepared by chromic acid oxidation. α-Bromo-β,γ-bis-(phenylsulfonyl)-propane results from acid permanganate oxidation of the disulfide.[338]

γ-Disulfones: Properties and Reactions. The γ-disulfones are high-melting, stable compounds which are unaffected by acids or by bromine. Phosphorus pentachloride reacts slowly with α,β-bis-(phenylsulfonyl)-ethane, and with chlorine even in diffused light a mixture of products results including sulfuryl chloride, ethylene chloride, benzenesulfonyl chloride, and chlorine derivatives of benzene.[339] In direct sunlight all the sulfur is converted into sulfuryl chloride.

γ-Disulfones are sharply differentiated from all other disulfones by their cleavage into an alcohol and sulfinate by alkali (Stuffer's rule).[333, 339] The reaction is slow for α,β-bis-(phenylsulfonyl)-ethane;[331] this requires eight days at 100° with dilute alkali. Ethylene

$$(C_6H_5SO_2CH_2)_2 + NaOH \rightarrow C_6H_5SO_2CH_2CH_2OH + C_6H_5SO_2Na$$

bis-(sulfonylacetic acid) reacts somewhat more rapidly.[340] With pro-

$$(CH_2SO_2CH_2COONa)_2 + NaOH \rightarrow$$
$$NaO_2SCH_2COONa + HOCH_2CH_2SO_2CH_2COONa$$

pylene bis-(sulfonylacetic acid) an unsaturated sulfone is formed.[335]

$$CH_3CH(SO_2CH_2COONa)CH_2SO_2CH_2COONa + NaOH \rightarrow$$
$$CH_3CH{=}CHSO_2CH_2COONa + NaO_2SCH_2COONa + H_2O$$

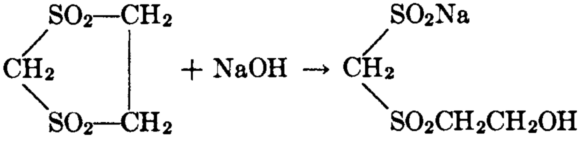
The reaction of acids of this class (as their sodium salts) with dilute alkali is bimolecular[335b] for hydroxyl-ion concentrations between 10^{-3} and 10^{-5}; the value of K increases with decreasing basicity of the solution. These acids also decompose in acid solution at 100° but here loss of carbon dioxide occurs and the rate decreases with increasing acidity of the solution.

Cleavage of γ-disulfones is also brought about by ammonia or ethylamine but not by aniline.[339] The β-phenylsulfonylethylamine reacts with more disulfone to give the secondary amine.

$$(C_6H_5SO_2CH_2)_2 + 2NH_3 \rightarrow C_6H_5SO_2NH_4 + C_6H_5SO_2CH_2CH_2NH_2$$

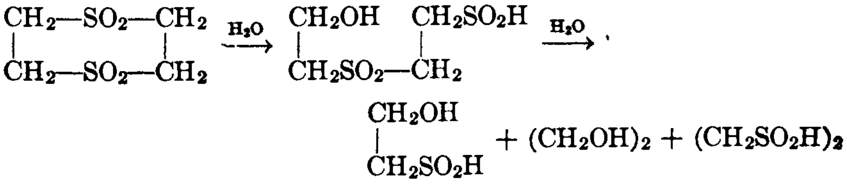
Since the primary products are a sulfinate and an alcohol, the cleavage of γ-disulfones by sodium amalgam must be due to the alkaline solution rather than the reducing action of the amalgam. Aqueous potassium cyanide converts α,β-bis-(phenylsulfonyl)-ethane into potassium benzenesulfinate and ethylene cyanide. The latter was largely hydrolyzed to succinic acid. Potassium hydrogen sulfide also reacts with this disulfone but the products were not determined. Vigorous oxidation with potassium permanganate yields benzenesulfonic acid, carbonic acid, oxalic acid, and sulfuric acid.[339]

γ-Disulfones in which the sulfur atoms form part of a ring system undergo cleavage with alkali just as do the chain compounds. Thus the 1,3-dithiacyclopentane tetroxide reacts as follows.[336b]



The free acid loses sulfur dioxide readily. 1,4-Dithiane tetroxide is likewise hydrolyzed in alkaline solution.[331, 336b, 341a] Here hydrolysis occurs at both sulfone groups.

$$HO_2SCH_2SO_2CH_2CH_2OH \rightarrow CH_3SO_2CH_2CH_2OH + SO_2$$

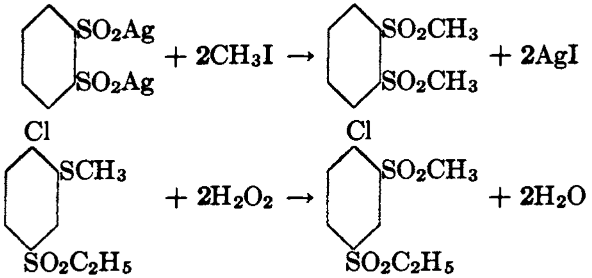


$$\begin{matrix} CH_2-SO_2-CH_2 \\ | \qquad\qquad | \\ CH_2-SO_2-CH_2 \end{matrix} \xrightarrow{H_2O} \begin{matrix} CH_2OH \quad CH_2SO_2H \\ | \qquad\qquad | \\ CH_2SO_2-CH_2 \end{matrix} \xrightarrow{H_2O} \begin{matrix} CH_2OH \\ | \\ CH_2SO_2H \end{matrix} + (CH_2OH)_2 + (CH_2SO_2H)_2$$

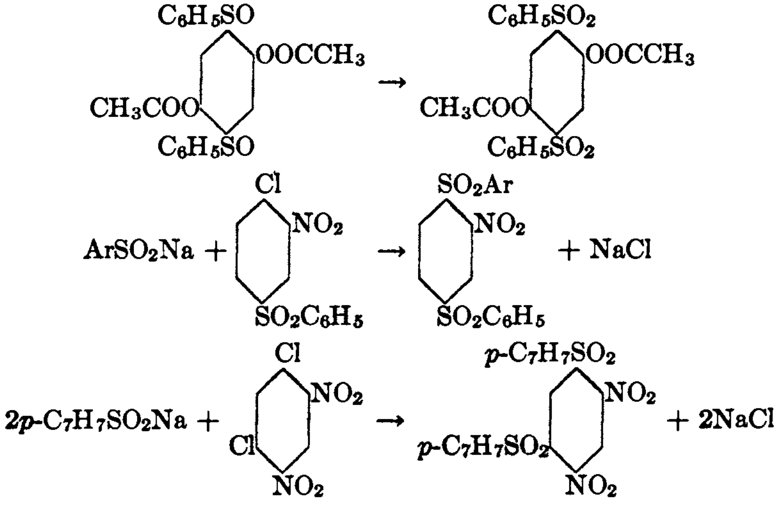
As will be seen later trisulfones having sulfone groups separated by two carbon atoms behave similarly.

The remarkable observation has been made by Waldron and Reid[186a] that the reduction of α,β-bis-(*p*-nitrophenylsulfonyl)-ethane with tin and hydrochloric acid apparently gives a diamino compound in which one sulfone group has been reduced to a sulfide. Since there is no other example on record of the easy reduction of a sulfone to a sulfide this reaction deserves further study. Purgotti[341b] has reported that α,β-bis-(*p*-chlorophenylsulfonyl)-ethane is cleaved into two moles of methyl *p*-chlorophenyl sulfone by zinc and hydrochloric acid. No other sulfones of this type have shown this behavior and the experiment should be repeated.

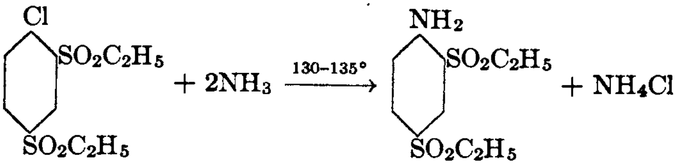
Arylene Disulfones. A number of sulfones are known which have both sulfur atoms attached to the same aromatic nucleus. The other groups may be alkyl or aryl. They have been prepared for the most part by a suitable modification of general methods already described such as the alkylation of a silver[342] or potassium[343] disulfinate, oxidation of a sulfide[342b,344] or of a sulfoxide,[345] and the reaction of an alkali sulfinate with an activated aryl halide.[346]



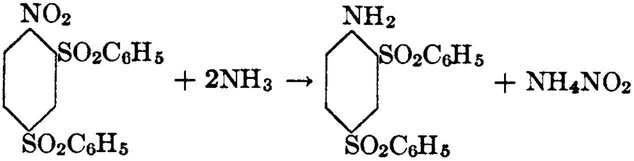
$$3m\text{-}C_6H_4(SCF_3)_2 + 8CrO_3 \rightarrow 3m\text{-}C_6H_4(SO_2CF_3)_2 + 4Cr_2O_3$$

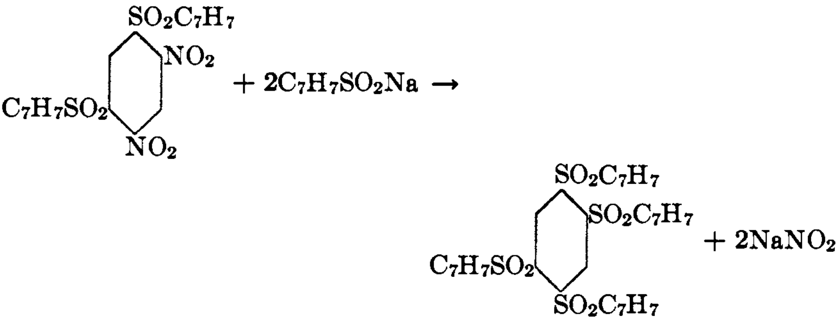


The marked activating effect of sulfone groups *ortho* and *para* to halogen forms the basis for patents on the synthesis of aminosulfones.[347] With alkali a phenol is formed.[342b]



The activation is evident also in nitrodisulfones as indicated by the equations.[346b, 348]

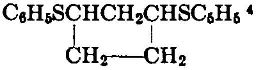
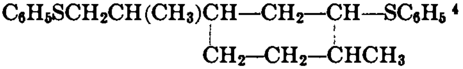




On the other hand 2,4-bis-(phenylsulfonyl)-toluene does not condense with benzaldehyde whereas the presence of one nitro group and a phenylsulfonyl group does induce the reaction.[349]

Miscellaneous Saturated Disulfones. Disulfones in which three or more carbon atoms intervene between the sulfone groups differ but little from monosulfones in either methods of preparation or reactions. Several such disulfones have been obtained in high yields by permanganate, chromic acid, or hydrogen peroxide oxidation of the corresponding sulfides. The α,γ-bis-(nitrophenylsulfonyl)-propanes of Table XXXV were prepared in the course of synthesizing a series of azo dyes suitable for determining the effect of the sulfone group on the color of the dyes. The sulfide needed to prepare α,γ-bis-(ethylsulfonyl)-propane was obtained as a by-product in the reaction of ethanethiol upon trimethylene chlorobromide in the presence of alkali.

TABLE XXXV

Sulfide Oxidized and Reference	M.P. of Sulfone, °C.
$CH_3S(CH_2)_3SCH_3$ [1]	155
$C_2H_5S(CH_2)_3SCH_3$ [1, 2]	184
$C_2H_5S(CH_2)_3SC_2H_5$ [9]	181–182
$C_6H_5CH_2S(CH_2)_3SCH_2C_6H_5$ [1, 5]	189
$2\text{-}NO_2C_6H_4S(CH_2)_3SC_6H_4NO_2\text{-}2$ [6]	156–157
$C_6H_5S(CH_2)_3SC_6H_5$ [3]	127–128
$4\text{-}NO_2C_6H_4S(CH_2)_3SC_6H_4NO_2\text{-}4$ [7]	208
$C_6H_5CH_2S(CH_2)_5SCH_2C_6H_5$ [8]	162–163
 $C_6H_5SCHCH_2CHSC_6H_5$ [4] $\quad CH_2—CH_2$	232–233
 $C_6H_5SCH_2CH(CH_3)CH—CH_2—CH—SC_6H_5$ [4] $\quad CH_2—CH_2—CHCH_3$	236–237

[1] Autenrieth and Wolff, *Ber.*, **32**, 1368 (1899).
[2] Stuffer, *Ber.*, **23**, 3234 (1890).
[3] Otto, *J. prakt. Chem.*, [2] **51**, 293 (1895).
[4] Posner, *Ber.*, **38**, 656 (1905).
[5] Autenrieth and Geyer, *Ber.*, **41**, 4254 (1908).
[6] Fromm, Benzinger, and Schäfer, *Ann.*, **394**, 327 (1912).
[7] Waldron and Reid, *J. Am. Chem. Soc.*, **45**, 2411 (1923).
[8] Foster and Reid, *ibid.*, **46**, 1944 (1924).
[9] Kretov and Toropova, *J. Gen. Chem.* (*U.S.S.R.*), **7**, 2009 (1937); *C.A.*, **32**, 518 (1938).

A few disulfones have been prepared from trimethylene bromide and an alkali sulfinate.

TABLE XXXVI

Sulfinate and Reference	M.P. of Sulfone, °C.
$C_6H_5SO_2Na$ [1]	127–128
$o\text{-}CH_3C_6H_4SO_2Na$ [2]	Oil
$p\text{-}CH_3C_6H_4SO_2Na$ [3]	124–125
$\beta\text{-}C_{10}H_7SO_2Na$ [4]	145

[1] Stuffer, *Ber.*, **23**, 3234 (1890).
[2] Tröger and Voigtländer-Tetzner, *J. prakt. Chem.*, [2] **64**, 528 (1896).
[3] Otto, *Ber.*, **24**, 1834 (1891); *J. prakt. Chem.*, [2] **51**, 296 (1895).
[4] Tröger and Artmann, *ibid.*, [2] **53**, 493 (1896).

None of these compounds reacts with dilute aqueous alkali but alcoholic potassium hydroxide at 120° has been shown [350] to react with α,γ-bis-(phenylsulfonyl)-propane and the p-tolyl analog as shown in the equation.

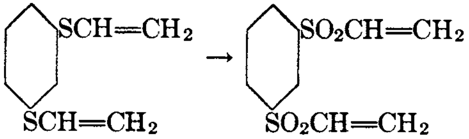
$$2C_6H_5SO_2(CH_2)_3SO_2C_6H_5 + 2KOH \rightarrow (C_6H_5SO_2CH_2CH_2CH_2)_2O + 2C_6H_5SO_2K + H_2O$$

The reduction of α,γ-bis-(o-nitrophenylsulfonyl)-propane with iron and acetic acid gives a compound which analyzed correctly for the diamino disulfide,[351] $(NH_2C_6H_4SCH_2)_2CH_2$. This unusual reduction of the sulfone group deserves further investigation.

Unsaturated Disulfones. Unsaturated disulfones are readily prepared by oxidation of the corresponding sulfides[352] with hydrogen peroxide or even potassium permanganate without attacking the olefin

$$p\text{-}C_7H_7SCH{=}CHSC_7H_7\text{-}p + 4H_2O_2 \rightarrow p\text{-}C_7H_7SO_2CH{=}CHSO_2C_7H_7\text{-}p + 4H_2O$$

linkage provided this is adjacent to even one sulfur atom.[353]



α,γ-Disulfonylpropenes have been prepared in a number of ways.[354] The most satisfactory procedure is shown in the equations; a mixture of isomers results.

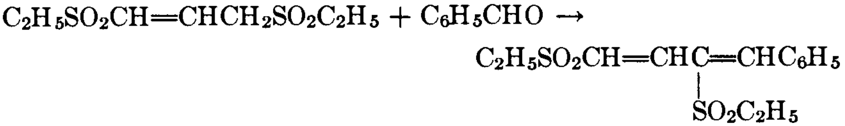
$$C_2H_5SO_2CH_2CHOHCH_2SO_2C_6H_5 \xrightarrow{PCl_5} C_2H_5SO_2CH_2CHClCH_2SO_2C_6H_5 \xrightarrow{C_5H_5N} C_2H_5SO_2CH{=}CHCH_2SO_2C_6H_5 \rightleftharpoons C_2H_5SO_2CH_2CH{=}CHSO_2C_6H_5$$

α,β-Bis-(*p*-tolylsulfonyl)-ethylene[352] is reduced by zinc and acetic acid to the saturated disulfone. With phenylhydrazine cleavage occurs.

$$(p\text{-}C_7H_7SO_2CH{=})_2 + 2C_6H_5NHNH_2 \rightarrow p\text{-}C_7H_7SO_2CH_2CH{=}N{-}NHC_6H_5 + p\text{-}C_7H_7SO_2H_3NNHC_6H_5$$

No reaction occurs with bromine. Ethylmagnesium bromide reacts readily[355] but the nature of the product was not determined.

α-Benzylsulfonyl-γ-ethylsulfonylpropene reacts with sodium or potassium alkoxides to give an alkali metal derivative of a sulfone having twice or three times the molecular weight of the original.[354] α,γ-Bis-(ethylsulfonyl)-propene condenses with benzaldehyde to form a butadiene derivative.



$$C_2H_5SO_2CH{=}CHCH_2SO_2C_2H_5 + C_6H_5CHO \rightarrow C_2H_5SO_2CH{=}CH\underset{\displaystyle SO_2C_2H_5}{\underset{|}{C}}{=}CHC_6H_5$$

The isomeric α-benzylsulfonyl-γ-ethylsulfonylpropenes are readily interconvertible. The reaction is rapid in methanol and slower in ethyl acetate or benzene or for the compounds alone above the melting point.

Ketodisulfones. A number of investigations dealing with disulfones derived from acetone are reported in the literature. α,γ-Bis-(phenylsulfonyl)-acetone has been prepared by the action of sodium benzenesulfinate upon at least four different halogen derivatives of acetone. α,γ-Dichloroacetone,[356] $\alpha,\alpha,\gamma,\gamma$-tetrachloroacetone,[357] α-phenylsulfonyl-γ-bromoacetone, and the γ,γ-dibromo compound[358] all yield the disulfone, the halogens not reacting by double decomposition being removed by reduction. α,γ-Bis-(*p*-fluorophenylsulfonyl)-acetone[359] has been obtained from diiodoacetone and the sulfinate. In Table XXXVII are listed the ketodisulfones obtained from halosulfonylketones and sulfinates by heating in alcohol solution.

TABLE XXXVII

α-SULFONYL-γ-BROMOKETONE AND REFERENCE	SODIUM SULFINATE	M.P. OF DISULFONE, °C.
$C_6H_5SO_2CH_2COCH_2Br$ [1]	$C_6H_5SO_2Na$	149
	p-$CH_3C_6H_4SO_2Na$	112
p-$ClC_6H_4SO_2CH_2COCH_2Br$ [2]	$C_6H_5SO_2Na$	129–130
	p-$ClC_6H_4SO_2Na$	166
	p-$CH_3C_6H_4SO_2Na$	163
	β-$C_{10}H_7SO_2Na$	167
p-$BrC_6H_4SO_2CH_2COCH_2Br$ [3]	*p*-$BrC_6H_4SO_2Na$	195
	o-$CH_3OC_6H_4SO_2Na$	160
	p-$CH_3C_6H_4SO_2Na$	163
	β-$C_{10}H_7SO_2Na$	165
o-$CH_3OC_6H_4SO_2CH_2COCH_2Br$ [3]	*o*-$CH_3OC_6H_4SO_2Na$	165
	p-$CH_3C_6H_4SO_2Na$	177
p-$CH_3OC_6H_4SO_2CH_2COCH_2Br$ [3]	*p*-$CH_3C_6H_4SO_2Na$	140
o-$C_2H_5OC_6H_4SO_2CH_2COCH_2Br$ [3]	*p*-$CH_3C_6H_4SO_2Na$	144
p-$C_2H_5OC_6H_4SO_2CH_2COCH_2Br$ [3]	*p*-$CH_3C_6H_4SO_2Na$	116
p-$CH_3C_6H_4SO_2CH_2COCH_2Br$ [1]	$C_6H_5SO_2Na$	112
	p-$CH_3C_6H_4SO_2Na$	152
β-$C_{10}H_7SO_2CH_2COCH_2Br$ [4]	$C_6H_5SO_2Na$	144
	p-$CH_3C_6H_4SO_2Na$	185
	β-$C_{10}H_7SO_2Na$	200

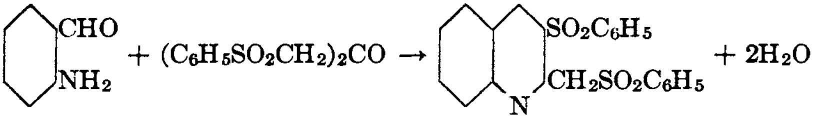
[1] R. and W. Otto, *J. prakt. Chem.*, [2] **36**, 427 (1887).
[2] Tröger and von Seelen, *ibid.*, [2] **105**, 208 (1923).
[3] Tröger and Pahle, *ibid.*, [2] **115**, 221 (1926).
[4] Tröger and Bolm, *ibid.*, [2] **55**, 411 (1897).

The chemical properties of the disulfones derived from acetone are similar to those of the β-ketosulfones already discussed (see p. 721). α,γ-Bis-(phenylsulfonyl)-acetone reacts with hydroxylamine, ammonia, thiophenol, and phenylhydrazine in the same manner as do ordinary ketones[360] but does not add hydrogen cyanide. With aqueous potassium hydroxide the following reaction occurs.

$$(C_6H_5SO_2CH_2)_2CO + KOH \rightarrow C_6H_5SO_2CH_3 + C_6H_5SO_2CH_2COOK$$

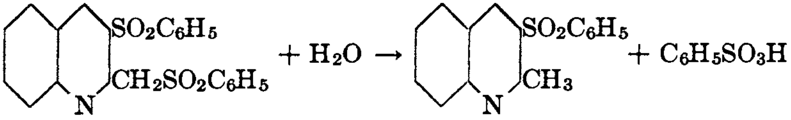
The reactivity of the ketones varies with the aryl groups. α,γ-Bis-(*p*-tolylsulfonyl)-acetone behaves precisely like the phenyl compound but α-phenylsulfonyl-γ-2-naphthylsulfonylacetone[361] not only does not react with hydrogen cyanide and sodium bisulfite but also is inert toward thiophenol and condenses with phenylhydrazine only when heated with it under pressure. α,γ-Bis-(2-naphthylsulfonyl)-acetone reacts with hydroxylamine only when the two compounds are heated under pressure in 50% alcohol at 140°.

By heating *o*-aminobenzaldehyde and α,γ-bis-(phenylsulfonyl)-acetone or its analogs at 160° or higher in a sealed tube there is formed a quinoline derivative[362] containing both sulfone groups intact.

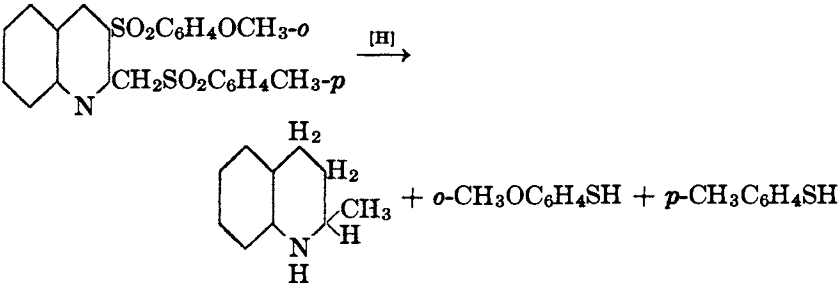


The results obtained in reactions of this kind are summarized in Table XXXVIII. The reaction time and temperature must be carefully controlled to obtain good yields of products.

These quinoline derivatives have no basic properties. Fusing with potassium hydroxide does not split off the sulfone groups but by heating with concentrated hydrochloric acid under pressure at 240° the α-phenylsulfonyl group is lost.

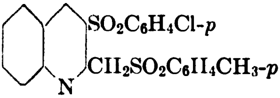
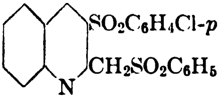
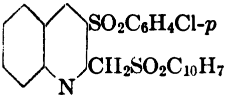
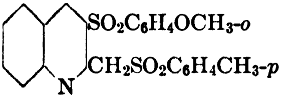
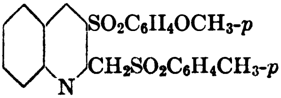
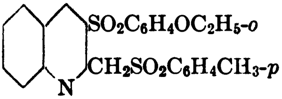
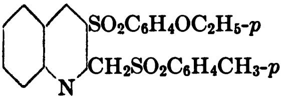
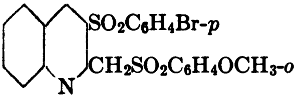
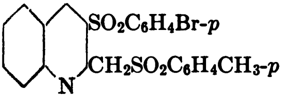
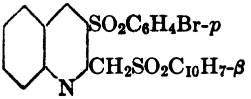


By reduction with tin and concentrated hydrochloric acid both sulfone groups are split off. These reactions were used in determining

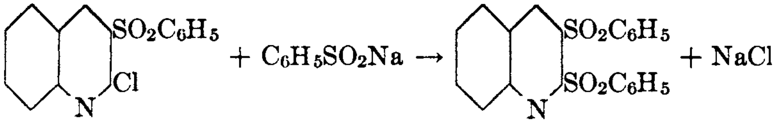


the structures shown in Table XXXVIII.

TABLE XXXVIII

Disulfone	Reaction Temp., °C., and Time	Formula of *unsym*-Quinoline Disulfone	M.P. of Quinoline Disulfone, °C.
$(\text{C}_6\text{H}_5\text{SO}_2\text{CH}_2)_2\text{CO}$	160, 2.5 hrs.	....	168
$(p\text{-ClC}_6\text{H}_4\text{SO}_2\text{CH}_2)_2\text{CO}$	165, 15 min.	....	197
$(p\text{-BrC}_6\text{H}_4\text{SO}_2\text{CH}_2)_2\text{CO}$	100, 3 days	....	132
$(p\text{-CH}_3\text{C}_6\text{H}_4\text{SO}_2\text{CH}_2)_2$	155, 15 min.	....	202
$(o\text{-CH}_3\text{OC}_6\text{H}_4\text{SO}_2\text{CH}_2)_2\text{CO}$	180, 2 hrs.	....	188
$\left.\begin{matrix} p\text{-ClC}_6\text{H}_4\text{SO}_2\text{CH}_2 \\ p\text{-CH}_3\text{C}_6\text{H}_4\text{SO}_2\text{CH}_2 \end{matrix}\right\rangle\text{CO}$	165, 10 min.		199–200
$\left.\begin{matrix} p\text{-ClC}_6\text{H}_4\text{SO}_2\text{CH}_2 \\ \text{C}_6\text{H}_5\text{SO}_2\text{CH}_2 \end{matrix}\right\rangle\text{CO}$	130–150, 20 min.		157
$\left.\begin{matrix} p\text{-ClC}_6\text{H}_4\text{SO}_2\text{CH}_2 \\ \beta\text{-C}_{10}\text{H}_7\text{SO}_2\text{CH}_2 \end{matrix}\right\rangle\text{CO}$	170, 20 min.		163
$\left.\begin{matrix} o\text{-CH}_3\text{OC}_6\text{H}_4\text{SO}_2\text{CH}_2 \\ p\text{-CH}_3\text{C}_6\text{H}_4\text{SO}_2\text{CH}_2 \end{matrix}\right\rangle\text{CO}$	160, 1 hr.		208
$\left.\begin{matrix} p\text{-CH}_3\text{OC}_6\text{H}_4\text{SO}_2\text{CH}_2 \\ p\text{-CH}_3\text{C}_6\text{H}_4\text{SO}_2\text{CH}_2 \end{matrix}\right\rangle\text{C=O}$	150, 2 hrs.		187
$\left.\begin{matrix} o\text{-C}_2\text{H}_5\text{OC}_6\text{H}_4\text{SO}_2\text{CH}_2 \\ p\text{-CH}_3\text{C}_6\text{H}_4\text{SO}_2\text{CH}_2 \end{matrix}\right\rangle\text{CO}$	150, 20 min.		194
$\left.\begin{matrix} p\text{-C}_2\text{H}_5\text{OC}_6\text{H}_4\text{SO}_2\text{CH}_2 \\ p\text{-CH}_3\text{C}_6\text{H}_4\text{SO}_2\text{CH}_2 \end{matrix}\right\rangle\text{CO}$	130, 30 min.		182
$\left.\begin{matrix} p\text{-BrC}_6\text{H}_4\text{SO}_2\text{CH}_2 \\ o\text{-CH}_3\text{OC}_6\text{H}_4\text{SO}_2\text{CH}_2 \end{matrix}\right\rangle\text{CO}$	100, 2 days		191
$\left.\begin{matrix} p\text{-BrC}_6\text{H}_4\text{SO}_2\text{CH}_2 \\ p\text{-CH}_3\text{C}_6\text{H}_4\text{SO}_2\text{CH}_2 \end{matrix}\right\rangle\text{CO}$	150, 25 min.		193
$\left.\begin{matrix} p\text{-BrC}_6\text{H}_4\text{SO}_2\text{CH}_2 \\ \beta\text{-C}_{10}\text{H}_7\text{SO}_2\text{CH}_2 \end{matrix}\right\rangle\text{CO}$	200, 2 hrs.		195

α,β-Bis-(phenylsulfonyl)-quinoline, differing from the compound given above by a methylene group, has been obtained from α-chloro-β-phenylsulfonylquinoline[363] and sodium benzenesulfinate.



Oxidation of the sulfide obtained by the reaction of thiophenol with phorone gives a disulfone[364] in which the keto group does not react with hydroxylamine, phenylhydrazine, semicarbazide, or thiophenol. It would be of interest to know the behavior of this compound toward

$$[(CH_3)_2C(SC_6H_5)CH_2]_2CO \xrightarrow{KMnO_4} [(CH_3)_2C(SO_2C_6H_5)CH_2]_2CO$$

dilute alkali as the analogous γ-di- and trisulfones undergo hydrolysis.

Trisulfones. The trisulfones in which the three sulfone groups are attached to a single carbon have been prepared by oxidation of sulfidedisulfones or the trisulfides. For example, bis-(ethylsulfonyl)-phenylsulfonylmethane results in 80% yield by oxidation of the disulfone with alkaline permanganate.[307a, 365]

$$Br_2C(SO_2C_2H_5)_2 \xrightarrow[NaOH]{C_6H_5SH} C_6H_5SCH(SO_2C_2H_5)_2 \rightarrow C_6H_5SO_2CH(SO_2C_2H_5)_2$$

The disulfone has also been synthesized[307a] as follows.

$$(C_2H_5SO_2)_2CH_2 + C_6H_5SO_2SC_6H_5 + NaOC_2H_5 \rightarrow (C_2H_5SO_2)_2CHSC_6H_5 + C_6H_5SO_2Na + C_2H_5OH$$

The trisulfones obtained by oxidation of sulfidedisulfones are tabulated below.

TABLE XXXIX

Sulfidedisulfone	Reagent	M.P. of Trisulfone, °C.
$C_6H_5SO_2CH(SCH_3)SO_2C_2H_5$ $CH_3SO_2CH(SC_6H_5)SO_2C_2H_5$	$KMnO_4$	216
$C_6H_5SCH(SO_2C_2H_5)_2$	Alk. $KMnO_4$	165–166
$C_6H_5SO_2CH(SCH_3)SO_2C_7H_7$-*p* $C_6H_5SO_2CH(SC_7H_7$-*p*$)SO_2CH_3$	H_2O_2	174
$C_6H_5SO_2CH(SC_6H_3Cl_2$-3,5$)SO_2CH_3$	H_2O_2	208

The compounds of the general formula $(RSO_2CH_2CH_2)_2SO_2$ where R is ethyl, *n*-butyl, or phenyl have been prepared by permanganate or chromic acid oxidation[366a] of the monosulfone, $(RSCH_2CH_2)_2SO_2$ or of the trisulfide. The corresponding benzyl monosulfone is readily converted to the trisulfone with hydrogen peroxide.[366b] Tris-(phenylsulfonyl)-methane has been prepared by the oxidation of phenyl trithioörthoformate,[366c,d] a reaction best carried out in two stages. With potassium permanganate in acid solution the disulfone is formed, which in alkaline solution is further oxidized to the trisulfone. The sulfidedisulfone is readily alkylated with methyl iodide in alkaline solution but oxidation of the product does not produce a satisfactory yield of the trisulfone which is, however, formed in a nearly quantitative yield by oxidation of the phenyl trithioörthoacetate. Ethyl

$$3C_6H_5SNa + CH_3CCl_3 \rightarrow (C_6H_5S)_3CCH_3 \rightarrow (C_6H_5SO_2)_3CCH_3$$

trithioörthoformate has not been oxidized to the trisulfone, loss of one of the sulfide groups occurring, but the corresponding orthoacetate, like the phenyl compound, is readily converted into the trisulfone. Oxidation of benzyl trithioörthoformate with permanganate gives two products separable by fractional crystallization. These are bis-(benzylsulfonyl)-methane and the sulfide-disulfone, $(C_6H_5CH_2SO_2)_2CHS-CH_2C_6H_5$. All attempts to oxidize the latter to the trisulfone were failures. Oxidation of an impure benzyl trithioörthobenzoate with permanganate was reported to give a very small yield of the trisulfone.

Oxidation of 1,2,2-tris-(ethylthiol)-propane, obtained from chloroacetone and ethanethiol, gives the trisulfone readily.[367] A cyclic sulfide, $C_6H_{12}S_3$, has also been converted to the trisulfone by permanganate oxidation.[368] A number of other miscellaneous trisulfones have been prepared by permanganate oxidation of the sulfides.[369] The reaction of sodium benzenesulfinate with 1,2,3-tribromopropane gives a small yield of the corresponding trisulfone.[367]

$$3C_6H_5SO_2Na + C_3H_5Br_3 \rightarrow C_3H_5(SO_2C_6H_5)_3 + 3NaBr$$

The trisulfones of the general formula $(RSO_2)_3CH$ are strongly acidic substances. They liberate carbon dioxide from carbonates in the cold and are not precipitated from aqueous solutions of their salts by acetic acid. Numerous attempts have been made to resolve trisulfones of the type $RSO_2CH(SO_2R')SO_2R''$ by fractional crystallization of their salts with active bases but without success.[307a] This result is in accord with the optical instability of the carbon in β-disulfones (see p. 735).

The reaction of sodium tris-(phenylsulfonyl)-methane with methyl iodide occurs to only a slight extent even in a sealed tube at high temperatures and with the silver salt the results were entirely negative. Tris-(phenylsulfonyl)-methane gives a quantitative yield of a halogen derivative when treated with chlorine or bromine in aqueous solution.[366d] Iodine does not react. Tris-(phenylsulfonyl)-chloromethane is much more stable to alkali than the bromo compound, the former being unaffected by aqueous alkali whereas the bromine compound decomposes rapidly. Alcoholic sodium hydroxide does react with the chloro compound, however. The products for both compounds are tris-(phenylsulfonyl)-methane and sodium benzenesulfonate. This behavior is analogous to that of the bis-(ethylsulfonyl)-dibromomethane already described (see p. 741).

Trisulfones having the three sulfonyl groups attached to the same carbon and not containing an acidic hydrogen are very stable toward acids and alkali. They dissolve in concentrated sulfuric acid without reacting. Warm alkaline permanganate however brings about oxidation.[366d]

$$(C_6H_5SO_2)_3CCH_3 \xrightarrow[NaOH]{KMnO_4} 3C_6H_5SO_3Na + CH_3COONa$$

The behavior toward alkali of trisulfones having any two sulfone groups attached to adjoining carbons is similar to that of the γ-disulfones. α,β,γ-Tris-(phenylsulfonyl)-propane[367] gives sodium benzenesulfinate and a mixture of sulfones; α,α,β-tris-(phenylsulfonyl)-ethane yields three molecules of the benzenesulfinate,[369b] and α,β,β-tris-(ethylsulfonyl)-propane gives the ethanesulfinate and a resin, probably from hydroxyacetone.[370]

$$C_2H_5SO_2CH_2C(SO_2C_2H_5)_2CH_3 + 3KOH \rightarrow 3C_2H_5SO_2K + [CH_3COCH_2OH] + H_2O$$

α-Phenylsulfonyl-β,β-bis-(ethylsulfonyl)-propane likewise loses all three sulfone groups as sulfinates.[369c] Bis-(β-benzylsulfonylethyl)-sulfone undergoes cleavage into two sulfinates and a sulfone.[371]

$$(C_6H_5CH_2SO_2CH_2CH_2)_2SO_2 + 2NaOH \rightarrow C_6H_5CH_2SO_2Na + HOCH_2CH_2SO_2Na + HOCH_2CH_2SO_2CH_2C_6H_5$$

The cyclic trisulfone described by Ray[368] reacts with barium hydroxide to yield a mixture of sulfinates.

$$2C_6H_{12}S_3O_6 + 2Ba(OH)_2 \rightarrow (HOCH_2CH_2SO_2C_2H_4SO_2)_2Ba + (HOC_2H_4SO_2)_2Ba$$

Tetra-, Penta-, and Hexasulfones. Although bis-(ethylsulfonyl)-methane does not condense with benzaldehyde or acetaldehyde it does react with formaldehyde, particularly in the presence of a trace of piperidine[372] to give a tetrasulfone. Homologs of this have been obtained from bis-(*n*-propylsulfonyl)-methane and the isopropyl-isomer. 1,3-Dithiacyclohexane tetroxide condenses with formaldehyde in the same manner but the cyclopentane analog behaves anomalously.

$$2(C_2H_5SO_2)_2CH_2 + HCHO \rightarrow [(C_2H_5SO_2)_2CH]_2CH_2 + H_2O$$

Despite the accumulation of polar groups these tetrasulfones are only slightly soluble in water. They are colorless, odorless, beautifully crystalline substances which give colorless solutions in sulfuric acid and oxidize very slowly with fuming nitric acid. They dissolve in cold 15% alkali from which they are precipitated by carbonic acid. Heating the alkaline solution to 100° brings about decomposition with formation of the disulfones from which the tetrasulfones were prepared. The formaldehyde was not recovered. Bromine replaces the acidic hydrogens, and the dibromo compounds with alkali regenerate the unsubstituted tetrasulfones.

$$[(C_2H_5SO_2)_2CH]_2CH_2 + H_2O \xrightarrow{NaOH} (C_2H_5SO_2)_2CH_2 + HCHO$$

$$[(C_2H_5SO_2)CH]_2CH_2 + 2Br_2 \rightarrow [(C_2H_5SO_2)_2CBr]_2CH_2 + 2HBr$$

Tetrasulfones which contain no acidic hydrogen have been obtained by Posner[373] by oxidation of the tetrasulfides resulting when diketones are condensed with thiols. The compounds prepared by this procedure are listed in Table XL. Since many diketones do not condense with four molecules of a thiol this method is of limited value. Nothing is known concerning the chemical properties of these tetrasulfones.

TABLE XL

SULFIDE	M.P. OF TETRASULFONE, °C.
$[CH_3C(SCH_2C_6H_5)_2\text{-}]_2$	195–196
$[CH_3C(SCH_2C_6H_5)_2CH_2]_2$	222–227 (decomp.)
$[CH_3C(SC_5H_{11}\text{-iso})_2CH_2]_2$	139–140
$[CH_3C(SC_6H_6)_2CH_2]_2$	244
$(CH_3)_2CHC(SCH_2C_6H_5)_2CH_2CH_2C(SCH_2C_6H_5)_2CH_3$	202–203

A series of tetrasulfones having the general formula $(RSO_2CH_2)_4C$ has been obtained by oxidation of the sulfides with excess hydrogen peroxide in acetic acid.[374] The compounds so prepared are listed in Table XLI. Noteworthy are the high melting points of what may be called the "filled molecules" and the alternations exhibited for the *n*-alkyl compounds above *n*-butyl.

TABLE XLI

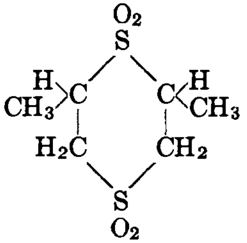
R of $(RSO_2CH_2)_4C$	M.P., °C. of Tetrasulfone
CH_3	>300
C_2H_5	185.5
n-C_3H_7	126.5
iso-C_3H_7	220.5
n-C_4H_9	111.5
i-C_4H_9	134
sec-C_4H_9	115
tert-C_4H_9	>300
n-C_5H_{11}	83.5
n-C_6H_{13}	85.5
n-C_7H_{15}	72
n-C_8H_{17}	80
n-C_9H_{19}	76
n-$C_{10}H_{21}$	78.8
n-$C_{11}H_{23}$	72.5
n-$C_{12}H_{25}$	78.3
C_6H_5	244
$C_6H_5CH_2$	179.5
$C_6H_5CH_2CH_2$	183

The linear pentasulfone, $(CH_3SO_2CH_2SO_2CH_2)_2SO_2$, has been prepared by oxidation of the sulfide with hydrogen peroxide.[375] A series of hexa-(alkylsulfonylmethyl)-benzenes have been made in excellent yields by oxidation of the hexasulfides with the same reagent.[376] These hexasulfones are characterized by ease of crystallization and high melting or decomposition points.

Polysulfones. It was observed by Solonina[377] that sulfur dioxide reacts with methyl, ethyl, and phenyl allyl ethers to give white, amorphous materials containing sulfur. A similar reaction was later reported[378] for simple olefins but this was not easily controlled until it was found that the reaction is catalyzed by oxygen,[379] ozone,[380] various peroxides,[380, 381] alkyl nitrites, metallic nitrates, sodium chlorate,[382b] and ultraviolet light.[382a, b] Cyclopentene[328c] reacts without a catalyst, as do the 1,3-dienes. In some of the earlier work ether and paraldehyde that had been exposed to the air were used as catalysts but peracetic acid and ascaridole, particularly in the presence of acid, proved to be more effective and convenient. In the presence of one or another of the catalysts mentioned most olefins react readily. Exceptions are trimethylethylene which reacts with difficulty[381e] and tetramethylethylene, pinene, and dihydronaphthalene.[383a] While vinyl chloride and bromide[383b, c] react readily, allyl and cinnamyl bromides not only do not form a polymer but prevent the reaction of other olefins[381e] even when present in small percentages. 1-Bromo-1-heptene was found to be inert as are olefinic acids that have the ethylenic linkage conjugated with the carboxyl group.[381c] Phenyl and alkylacetylenes also form polymers but dialkylacetylenes and allene do not.[384]

Polymer formation is slightly exothermic, occurs with a contraction of volume, and only in the liquid phase.[382b] The reactions show a peculiar "ceiling temperature" in some instances. Thus in the presence of lithium nitrate isobutylene reacts readily at 4° but not at all at 25°.

It has been mentioned previously that disulfones of the general formula $[RSO_2CH_2]_2$ are cleaved by alkali and this reaction makes possible the elucidation of the structures of the olefin-sulfur dioxide polymers. Ethylene polysulfone reacts with boiling barium hydroxide to give a barium sulfinate and "hydroxydiethylene sulfone." The propylene polymer[381b] dissolves readily in cold dilute sodium hydroxide; acidification of the solution gives a nearly quantitative yield of a cyclic disulfone whose structure was proved by alkaline degradation to sodium 1-methylsulfonylpropane-2-sulfinate and acetaldehyde. The



$$\xrightarrow{\text{NaOH}} CH_3SO_2CH_2CH(CH_3)SO_2Na + [CH_3CHO]_x$$

same products are obtained by boiling the polymer with 10% aqueous sodium hydroxide. The sulfonate obtained by oxidation of the sulfinate was synthesized from propylene bromohydrin and identified as

$$CH_3CHOHCH_2Br \xrightarrow{CH_3SNa} CH_3CHOHCH_2SCH_3 \xrightarrow{SOCl_2}$$

$$CH_3CHClCH_2SCH_3 \xrightarrow{Na_2SO_3} CH_3CH(SO_3Na)CH_2SCH_3 \xrightarrow{KMnO_4}$$

$$CH_3CH(SO_3Na)CH_2SO_2CH_3 \xrightarrow{PCl_5} CH_3CH(SO_2Cl)CH_2SO_2CH_3$$

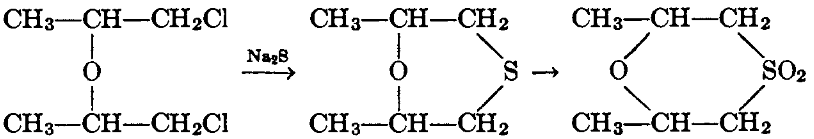
the acid chloride and anilide. The polymer is therefore of the "head-to-head" and "tail-to-tail" type indicated in the formula. It is probable that the initial alkaline cleavage product is the hydroxysulfone-

$$[\text{—}CH(CH_3)CH_2SO_2CH_2CH(CH_3)SO_2CH(CH_3)CH_2SO_2]_n$$

sulfinate shown as this could break down further to give acetaldehyde. Treating the polymer with hot sodium carbonate gave a small amount

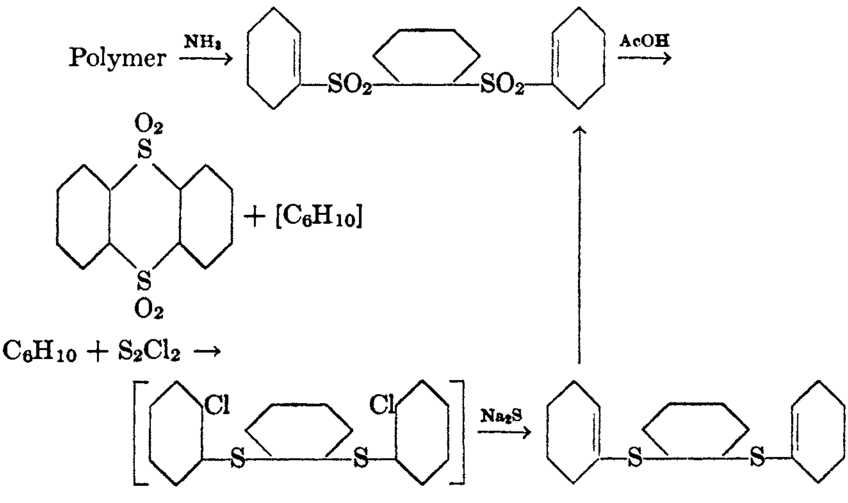
$$\text{Polymer} \rightarrow CH_3CHOHCH_2SO_2CH_2CH(CH_3)SO_2Na$$

of a cyclic ether sulfone. It is not clear how this arises. It was synthesized from bis-(β-chloroisopropyl) ether.



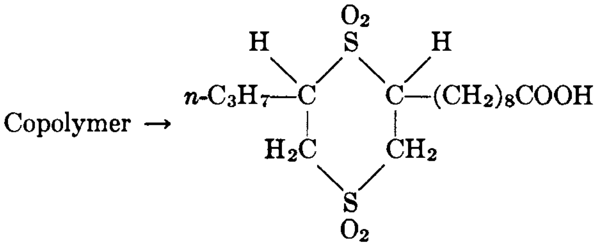
Since the propylene polysulfone is acidic and with phosphorus pentachloride gives an acid chloride that yields an anilide one end group may be that of a sulfonic acid formed by the addition of water to the ends of the polymer molecule. From analysis of the anilide it was concluded that the polymer had a molecular weight [888a] of about 50,000 while viscosity measurements pointed to a somewhat higher value.

Polysulfones from other olefins containing terminal double bonds including 1-pentene,[882a] styrene, and undecylenic acid have chemical properties similar to those of the propylene polymer. On the other hand the products from cyclohexene and other olefins containing only secondary or tertiary carbons and also those of the isobutylene type behave much differently toward alkali. Refluxing with aqueous sodium hydroxide yields sodium sulfite and the original olefin as well as more complex products. The 2-pentene polymer gives a dipentenyl sulfone as well as 2-pentene and the isobutylene polymer gives almost entirely the original olefin but that from cyclohexene is converted into a complex mixture of products including cyclohexene, cyclohexenesulfinic acid, an octahydrobiphenyl, a bis-(cyclohexenyl) sulfone, dodecahydrophenoxathiin dioxide, and unidentified compounds.[881a] The degradation of the cyclohexene polymer with liquid ammonia is more clear-cut, producing an unstable disulfone which was also synthesized from the sulfide.[885]



The vinyl chloride and bromide polymers differ from the others in that two moles of the halide combines with one of sulfur dioxide.[383b,c] They react with ammonia and aniline. With 20% sodium hydroxide the vinyl chloride polymer breaks down to give acetaldehyde, sodium chloride, and a polymeric substance containing the sulfur. On this basis the structure assigned[383c] to the vinyl chloride polysulfone was $-(SO_2CHClCH_2CHClCH_2)_n-$ and the product containing the sulfur after alkali degradation was believed to come from the polymerization of sodium acetaldehydesulfinate.

Several interesting copolymers have been prepared.[385] They contain the olefin groups in about the ratio that the olefins are present in the reaction mixture. The compound from 1-pentene and undecylenic acid is of particular interest as it was found to have a definite structure rather than having a probability type of distribution for the olefin units. Treatment with liquid ammonia gave a high yield of the disulfone indicated.



With any other than the alternating head-to-head, tail-to-tail arrangement of units considerable quantities of the symmetrically substituted sulfones would be formed.

The polymers obtained from alkylacetylenes and sulfur dioxide[381c,384,386] are less stable than those from olefins, losing one-half of their sulfur dioxide upon heating to 100–140°. The phenylacetylene polymer is broken down by alkali into sodium sulfite (50%), benzoic acid (20%), benzyl methyl sulfone (8%), and a trace of acetophenone, which do not serve to establish unequivocally its structure.

Pyrolysis of the sulfone from *n*-propylacetylene(1-pentyne) by heating in dioxane solution gives up to 22% of a crystalline sulfone which corresponds in composition to a di-*n*-propylthiophene-S-dioxide. This compound gave two dihydro derivatives but could not be completely reduced and hence could not be compared with the cyclic saturated sulfones that were synthesized.[386]

A number of patents have been issued which deal with the possible uses of olefin polysulfones in the synthetic resin field.[387] Their reaction with alkaline reagents and lack of stability toward heat are limiting factors in any extensive utilization.

Polymeric sulfones such as those obtained by the permanganate oxidation of the polymeric hexamethylene or tetradecamethylene sulfides have been described in the patent literature[388] as suitable for the preparation of a variety of commercial products.

REFERENCES

1. Freiman and Sugden, *J. Chem. Soc.,* 263 (1928).
2. Coop and Sutton, *Trans. Faraday Soc.,* **35,** 505 (1939).
3. Sutton, New, and Bentley, *J. Chem. Soc.,* 652 (1933).
4. DeVries and Rodebush, *J. Am. Chem. Soc.,* **53,** 2888 (1923).
5. Bergmann and Tschudnowsky, *Ber.,* **65B,** 457 (1932).
6. Hampson, Farmer, and Sutton, *Proc. Roy. Soc.,* **143A,** 147 (1933).
7. Lister and Sutton, *Trans. Faraday Soc.,* **35,** 495 (1939).
8. Maclean and Adams, *J. Am. Chem. Soc.,* **55,** 4683 (1933).
9. Lüttringhaus and Buchholz, *Ber.,* **72B,** 2057 (1939).
10. Staudinger and Pfenninger, *Ber.,* **49,** 1941 (1916).
11. Zincke and Brune, *Ber.,* **41,** 902 (1908).
12. Hochberg and Bonhoeffer, *Z. physik. Chem.,* **184A,** 419 (1939).
13. Ruzicka, Goldberg, and Meister, *Helv. Chim. Acta,* **23,** 559 (1940).
14. Pfiffner and North, *J. Biol. Chem.,* **134,** 781 (1940).
15. Landers, U. S. pat., 1,936,721, *C.A.,* **28,** 1049 (1934); German pat., 562,824, *C.A.,* **27,** 998 (1933).

16*a*. Loudon, *J. Chem. Soc.,* 537 (1935). *b*. Livingston and Loudon, *ibid.,* 246 (1937).

17. Olivier, *Rec. trav. chim.,* **33,** 91 (1914).
18. Olivier, *ibid.,* **33,** 244 (1914).
19. Olivier, *Rec. trav. chim.,* **35,** 166 (1915).

20*a*. Beckurts and Otto, *Ber.,* **11,** 2066 (1878). *b*. Huismann, U. S. pat., 2,224,964, *C.A.,* **35,** 2159 (1941).

21. Parisi, *Ann. chim. applicata,* **15,** 121 (1925); *C.A.,* **19,** 2557 (1925).
22. Mikeska and Bogert, *J. Am. Chem. Soc.,* **57,** 2121 (1935).
23. Crowell and Raiford, *ibid.,* **42,** 145 (1920).
24. Huntress and Carten, *ibid.,* **62,** 511 (1940).
25. Steiger, *Helv. Chim. Acta,* **13,** 173 (1930); Harding, *J. Soc. Chem. Ind.,* **44,** 138 (1925); Wynne, *J. Chem. Soc.,* 696 (1936); Child, *ibid.,* 715 (1932); Dziewoński, Grünberg, and Schoen, *C.A.,* **25,** 5419 (1931).
26. Steinkopf and Hübner, *J. prakt. Chem.,* [2] **141,** 193 (1934).
27. Steinkopf and Buchheim, *Ber.,* **54B,** 2963 (1921).
28. Krafft and Vorster, *Ber.,* **26,** 2813 (1893).
29. Carr, U. S. pat., 2,000,061, *C.A.,* **29,** 4027 (1935).
30. Michael and Weiner, *J. Am. Chem. Soc.,* **58,** 296 (1936).

31*a*. Michael and Adair, *Ber.,* **10,** 583 (1877). *b*. Kuczyński, Kuczyński, and Sucharda, *Roczniki Chem.,* **18,** 625 (1938); *C.A.,* **34,** 3246 (1940).

32. Fouque and La Croix, *Bull. soc. chim.,* **33,** 180 (1923).
33. Meyer, *Ann.,* **433,** 327 (1927).
34. Baumann and Walter, *Ber.,* **26,** 1131 (1893).
35. R. Otto and W. Otto, *Ber.,* **21,** 992 (1888).
36. Loveń, *Ber.,* **17,** 2819 (1884).
37. R. Otto and W. Otto, *Ber.,* **21,** 998 (1888).

38. Tröger and Uhde, *J. prakt. Chem.*, [2] **59**, 334 (1899).

39. Köhler and Reimer, *Am. Chem. J.*, **31**, 176 (1904).

40. Fuchs, *Monatsh.* **53** and **54**, 438 (1929).

41. Schimmelschmidt and Thomae, U. S. pat., 1,939,416, *C.A.*, **28**, 1716 (1934); French pat., 746,410, *C.A.*, **27**, 4684 (1933); British pat., 404,794, *C.A.*, **28**, 4247 (1934).

42. Otto, *J. prakt. Chem.*, [2] **40**, 527 (1889); *Ber.*, **19**, 1835 (1886); Ramberg, *Z. physik. Chem.*, **34**, 586 (1900).

43. Tröger and Kroseberg, *J. prakt. Chem.*, [2] **87**, 73 (1913).

44. Tröger and Hille, *ibid.*, [2] **71**, 216 (1905).

45. Tröger and Lux, *Arch. Pharm.*, **247**, 646 (1909).

46. Reuterskiöld, *J. prakt. Chem.*, [2] **127**, 269 (1930).

47. Otto, *Ber.*, **21**, 95 (1888).

48. Strecker, *Ber.*, **43**, 1136 (1910); Ferns and Lapworth, *J. Chem. Soc.*, **101**, 284 (1912).

49. Gilman, Beaber, and Myers, *J. Am. Chem. Soc.*, **47**, 2047 (1925).

50. Gilman and Nelson, *Rec. trav. chim.*, **55**, 518 (1936).

51. Whitmore and Thurman, *J. Am. Chem. Soc.*, **45**, 1068 (1923).

52. Otto, *Ber.*, **18**, 248 (1885).

53. Frankland and Lawrance, *Ber.*, **12**, 846 (1879).

54. Freund, *Ann.*, **120**, 81 (1861).

55. Bergmann and Fujise, *Ann.*, **483**, 65 (1930).

56. Witte, Tohl, and Eberhard, *Ber.*, **26**, 2941 (1893).

57. Arcus, Balfe, and Kenyon, *J. Chem. Soc.*, 485 (1938).

58*a*. Vogt and Henninger, *Ann.*, **165**, 375 (1873). *b*. Hinsberg, *Ber.*, **50**, 473 (1917).

59. Ziegler and Connor, *J. Am. Chem. Soc.*, **62**, 2596 (1940).

60. v. Oefele, *Ann.*, **127**, 370 (1863); **132**, 87 (1864).

61. Grabowsky, *Ann.*, **175**, 350 (1875).

62. Otto and Gruber, *Ann.*, **154**, 193 (1869); Otto, *Ber.*, **12**, **1175** (1879).

63. Strecker and Spitaler, *Ber.*, **59B**, 1754 (1926).

64. Ley and König, *Z. physik. Chem.*, **41B**, 365 (1938).

65. Mohler, *Helv. Chim. Acta*, **20**, 1188 (1937).

66. Gibson, Graham, and Reid, *J. Chem. Soc.*, **123**, 874 (1923).

67. Mikeska, Farinacci, and Bogert, *J. Am. Chem. Soc.*, **58**, 1869 (1936).

68. Wood and Ayliffe, *Phil. Mag.*, **21**, 321 (1936).

69. Smith and Andrews, *J. Am. Chem. Soc.*, **53**, 3644 (1931).

70*a*. Otto, *Ber.*, **13**, 1278 (1880). *b*. Beckmann, *J. prakt. Chem.*, [2] **17**, 455 (1878).

71. Otto, *Ber.*, **18**, 248 (1885); *Ann.*, **136**, 154 (1865).

72. Krafft and Vorster, *Ber.*, **26**, **2815** (1893).

73. Böeseken, *Rec. trav. chim.*, **30**, 137 (1911).

74. Gibson, *J. prakt. Chem.*, [2] **142**, 218 (1935).

75. Kliger, *J. Gen. Chem.* (*U.S.S.R.*), **3**, 904 (1933); *C.A.*, **28**, 3051 (1934).

76. Lange and Haupt, *J. Am. Chem. Soc.*, **51**, **2277** (1929).

77. Kekulé and Szuch, *Chem. Z.*, **44** (1868); Jacobsen, *Ber.*, **20**, 900 (1887); Jacobsen and Schnapauff, *Ber.*, **18**, **2843** (1885).

78. Otto and Ostrop, *Ann.*, **141**, 96 (1867).

79. Otto and Gruber, *Ann.*, **149**, 179 (1869).

80. Spring and Winssinger, *Ber.*, **15**, **445** (1882).

81. Bourgeois and Abraham, *Rec. trav. chim.*, **30**, 407 (1911).
82. Böeseken and Van Oeckenburg, *ibid.*, **33**, 321 (1914).
83. Spring and Winssinger, *Ber.*, **17**, 538 (1884).
84. Waldron and Reid, *J. Am. Chem. Soc.*, **45**, 2399 (1923).
85. Fenton and Ingold, *J. Chem. Soc.*, 3127 (1928).
86. Fenton and Ingold, *ibid.*, 2338 (1929).
87. Fenton and Ingold, *ibid.*, 708 (1930).
88. Otto, *Ber.*, **19**, 2425 (1886); Eikhman, Shemyakin, and Vozhdaeva, *Anilinokrasochnaya Prom.*, **4**, 523 (1934); *C.A.*, **29**, 2520 (1935).
89. Fenton and Ingold, *J. Chem. Soc.*, 705 (1930).
90. Bradley, *ibid.*, 458 (1938).
91. Twist and Smiles, *ibid.*, **127**, 1248 (1925).
92. Bennett and Youle, *ibid.*, 1816 (1938).
93. Ipatieff and Friedman, *J. Am. Chem. Soc.*, **61**, 684 (1939); Ipatieff, Pines, and Friedman, *ibid.*, **60**, 2731 (1938).
94. Baldwin and Robinson, *J. Chem. Soc.*, 1445 (1932).
95. Ingold, Ingold, and Shaw, *ibid.*, 813 (1927).
96. Chatterjee and Robinson, *ibid.*, 2780 (1927).
97. Martinet and Haehl, *Compt. rend.*, **173**, 775 (1921).
98. Buehler and Masters, *J. Org. Chem.*, **4**, 264 (1939).
99*a*. Loudon and Robson, *J. Chem. Soc.*, 242 (1937). *b*. Ullmann and Korselt, *Ber.*, **40**, 641 (1907).
100. Groves and Turner, *ibid.*, 509 (1929).
101*a*. Chardonnens and Venetz, *Helv. Chim. Acta*, **22**, 853 (1939). *b*. MacLean and Adams, *J. Am. Chem. Soc.*, **55**, 4683 (1933).
102. Pollak, Heimberg-Krauss, Katscher, and Lustig, *Monatsh.*, **55**, 358 (1930).
103*a*. Soc. pour l'ind. chim. à Bâle, French pat., 825,728, *C.A.*, **32**, 6667 (1938). *b*. I. G. Farbenind. A.-G., French pat., 677,458, *C.A.*, **24**, 3250 (1930).
104. Todd and Shriner, *J. Am. Chem. Soc.*, **56**, 1382 (1934).
105. Loudon and Robson, *J. Chem. Soc.*, 242 (1937); Loudon and Shulman, *ibid.*, 1618 (1938); Loudon, *ibid.*, 902 (1939).
106. Königs and Wylezich, *J. prakt. Chem.*, [2] **132**, 24 (1931).
107. Holt and Reid, *ibid.*, **46**, 2329 (1924).
108*a*. Shriner, Struck, and Jorison, *ibid.*, **52**, 2068 (1930). *b*. Fromm and Gaupp, *Ber.*, **41**, 3419 (1908); Fromm and Erfurt, *Ber.*, **42**, 3823 (1909). *c*. Connor, Fleming, and Clayton, *J. Am. Chem. Soc.*, **58**, 1386 (1936).
109. Shriner and Greenlee, *J. Org. Chem.*, **4**, 242 (1939).
110. Fromm and Wittman, *Ber.*, **41**, 2270 (1908).
111. Tröger and Nolte, *J. prakt. Chem.*, [2] **101**, 136 (1920).
112. Otto and Engelhardt, *Ber.*, **21**, 659 (1888).
113. Otto, *Ber.*, **21**, 652 (1888).
114*a*. Tröger and Hille, *J. prakt. Chem.*, [2] **71**, 218 (1905). *b*. Ramberg and Bäcklund, *Arkiv. Kemi, Mineral. Geol.*, **13A**, No. 27, 50 pp. (1940); *C.A.*, **34**, 4725 (1940).
115. Cashmore and McCombie, *J. Chem. Soc.*, **123**, 2884 (1923).
116. Cashmore, *ibid.*, **123**, 1738 (1923).
117. Otto, *J. prakt. Chem.*, [2] **30**, 329 (1884).
118. Baddeley and Bennett, *J. Chem. Soc.*, 261 (1933).
119. Otto, *Ann.*, **283**, 188 (1894).
120. Kuchárik and Telbisz, *Orvosi Hetilap*, **83**, 734 (1939); *C.A.*, **33**, 8328 (1939).

121. Magne and Trimbach, *Bull. soc. chim. biol.*, **19**, 1082 (1937).

122. Marshall and Williams, *J. Pharmacol.*, **16**, 259 (1920); Peters, *Nature*, **138**, 327 (1936); Berenblum, Kendal, and Orr, *Biochem. J.*, **30**, 709 (1936); Berenblum and Wormall, *ibid.*, **33**, 75 (1939).

123. Hinsberg, *Ber.*, **62B**, 127 (1929); **64B**, 2500 (1931); **69B**, 492 (1936); **70B**, 2027 (1937).

124. Goodman and Lowy, *J. Am. Chem. Soc.*, **60**, 2155 (1938).

125. Young, *Ind. Eng. Chem., Anal. Ed.*, **10**, 686 (1938).

126. Duin and Lennep, *Rec. trav. chim.*, **39**, 145 (1920).

127. I. G. Farbenind. A.-G., French pat., 809,373, *C.A.*, **31**, 6768 (1937).

128. Moureu, Dufraise, and Lotte, *Compt. rend.*, **180**, 993 (1925).

129. Henderson, Agruss, and Ayers, *Ind. Eng. Chem., Anal. Ed.*, **12**, 1 (1940).

130. Wood, Lowry, and Faragher, *Ind. Eng. Chem.*, **16**, 1116 (1924).

131. Meyer, *Chem. Zentr.*, I, 455 (1901); *J. prakt. Chem.*, [2] **63**, 167 (1901); Kohler and Reimer, *Am. Chem. J.*, **31**, 163 (1904).

132. Otto and Tröger, *Ber.*, 26, 944 (1893); Otto, *J. prakt. Chem.*, [2] **30**, 171, 321, 356 (1884); Tröger and Budde, *ibid.*, [2] **66**, 130 (1902).

133. Otto, *ibid.*, [2] **51**, 286 (1895).

134. Fenton and Ingold, *J. Chem. Soc.*, 2338 (1929); Hunt and Marvel, *J. Am. Chem. Soc.*, **57**, 1691 (1935).

135*a*. Otto, *J. prakt. Chem.*, [2] **30**, 355 (1884). *b*. Baddeley and Bennett, *J. Chem. Soc.*, 46 (1933).

136. Kent and Smiles, *ibid.*, 422 (1934).

137. Galbraith and Smiles, *ibid.*, 1234 (1935).

138. Fromm and Jörg, *Ber.*, **58B**, 304 (1925).

139. Wrede and Zimmermann, *Z. physiol. Chem.*, **148**, 65 (1925).

140. Henkel et Cie, G.m.b.H., German pat., 685,241, *C.A.*, **34**, 3763 (1940); Soc. pour l'ind. chim. à Bâle, Swiss pat., 207,645, *C.A.*, **35**, 3009 (1941).

141. Otto, *J. prakt. Chem.*, [2] **30**, 202 (1884).

142. Kirstahler and Kaiser, German pat., 676,273, *C.A.*, **33**, 6344 (1939).

143. Tröger and Budde, *J. prakt. Chem.*, [2] 66, 130 (1902).

144. Rojahn and Lemme, *Arch. Pharm.*, **263**, 612 (1925).

145. Tröger and Budde, *J. prakt. Chem.*, [2] 66, 149 (1902); Gauntlett and Smiles, *J. Chem. Soc.*, **127**, 2745 (1925); Holmes, Ingold, and Ingold, *ibid.*, 1684 (1926).

146. Heppenstall and Smiles, *ibid.*, 899 (1938).

147. Holt and Reid, *J. Am. Chem. Soc.*, 46, 2333 (1924).

148. Zincke and Dereser, *Ber.*, **51**, 352 (1918).

149. Rittler, German pat., 555,409, *C.A.*, **26**, 5105 (1926).

150. Rittler, German pat., 532,403, *C.A.*, **26**, 153 (1926).

151. Simons, Archer, and Randall, *J. Am. Chem. Soc.*, **62**, 485 (1940).

152*a*. McClement and Smiles, *J. Chem. Soc.*, 1016 (1937). *b*. Kent and Smiles, *ibid.*, 422 (1934). *c*. Galbraith and Smiles, *ibid.*, 1234 (1935). *d*. Levy, Rains, and Smiles, *ibid.*, 3264 (1931). *e*. Warren and Smiles, *ibid.*, 1040 (1932). *f*. Warren and Smiles, *ibid.*, 2207 (1931). *g*. Levi and Smiles, *ibid.*, 1488 (1932).

153*a*. Zehenter, *Monatsh.*, **33**, 333 (1912). *b*. J. R. Geigy A.-G., British pat., 471,010, *C.A.*, **32**, 1135 (1938). *c*. Schäfer, U. S. pat., 2,122,958, *C.A.*, **32**, 6773 (1938).

154. Zehenter, *Monatsh.*, **37**, 587 (1916).

155. Zehenter, *ibid.*, **40**, 377 (1920); Zehenter, Bohunek, and Nowotny, *J. prakt. Chem.*, [2] **121**, 223 (1929).

156. Zehenter, *ibid.*, [2] **137**, 216 (1933).

157. Zehenter and Ripl, *ibid.*, **139**, 309 (1934).

158. Zehenter and Gosch, *ibid.*, [2] **123**, 276 (1929).

159. Zehenter and Plass, *ibid.*, [2] 127, 263 (1930).

160. Jambuserwala, Holt, and Mason, *J. Chem. Soc.*, 373 (1931).

161. Hinsberg, *Ber.*, **50**, 953 (1917); 58B, 1335 (1925); Borsche and Pommer, *Ber.*, **54B**, 102 (1921).

162. Borsche and Franke, *Ann.*, **450**, 75 (1926).

163. Hinsberg, *J. prakt. Chem.*, [2] 90, 345 (1914); **91**, 307 (1915); **93**, 277 (1916).

164. Warren and Smiles, *J. Chem. Soc.*, 1327 (1930).

165. Coats and Gibson, *ibid.*, 442 (1940).

166. Hinsberg, *Ber.*, **52B**, 28 (1919); **57B**, 838 (1924); **58B**, 1335 (1925).

167. Jones, *J. Chem. Soc.*, 1854 (1936).

168. Schütte, U. S. pat., 2,179,800, *C.A.*, **34**, 1874 (1940); French pat., 840,520, *C.A.*, **33**, 8052 (1939); British pat., 494,042, *C.A.*, **33**, 2756 (1939).

169. J. R. Geigy A.-G., French pat., 819,370, *C.A.*, **32**, 2247 (1938); French pat., 823,194, *C.A.*, **32**, 5535 (1938); Bunge and Tischbein, German pat., 693,770, *C.A.*, **35**, 4876 (1941).

170. Guthke, U. S. pat., 2,174,287, *C.A.*, **34**, 906 (1940); German pat., 677,126, *C.A.*, **33**, 6998 (1939).

171. J. R. Geigy A.-G. and Hughes, British pat., 504,994, *C.A.*, **33**, 8052 (1939); British pat., 493,997, *C.A.*, **33**, 2756 (1939).

172. I. G. Farbenind. A.-G., German pat., 675,775, *C.A.*, **33**, 7145 (1939).

173. J. R. Geigy A.-G., German pat., 676,116, *C.A.*, **33**, 6643 (1939).

174. Schneider, *Ann.*, **386**, 344 (1912).

175. Schneider, *Ann.*, **375**, 225 (1910).

176. Schneider and Kauffmann, *Ann.*, **392**, 7 (1912).

177. Mylius, *Ber.*, **49**, 1100 (1916).

178. Schneider, *Ber.*, **41**, 4468 (1908).

179. Lawson and Reid, *J. Am. Chem. Soc.*, **47**, 2821 (1925).

180. Gabriel and Colmann, *Ber.*, **44**, 3628 (1911).

181. Walter, *Ber.*, **27**, 3046 (1894).

182*a*. Ufer, U. S. pat., 2,081,718, *C.A.*, **31**, 5179 (1937); British pat., 453,443, *C.A.*, **31**, 1038 (1936); French pat., 800,535, *C.A.*, **30**, 8640 (1936). *b*. Schneider, Clibbens, Hullweck, and Steibelt, *Ber.*, **47**, 1254 (1914).

183. Gabriel and Colman, *Ber.*, **44**, 3628 (1911).

184. Modersohn, German pat., 634,331, *C.A.*, **31**, 270 (1937); U. S. pat., 2,077,529, *C.A.*, **31**, 4135 (1937).

185. Tröger and Nolte, *J. prakt. Chem.*, [2] **101**, 136 (1920).

186*a*. Waldron and Reid, *J. Am. Chem. Soc.*, **45**, 2405 (1923). *b*. Schumacher, Scherer, and Müller, U. S. pat., 2,191,062, *C.A.*, **34**, 4588 (1940).

187. Zerweck, Steiger, and Ritter, U. S. pat., 2,119,123, *C.A.*, **32**, 5640 (1938); French pat., 816,727, *C.A.*, **32**, 2366 (1938); Swiss pat., 190,616, *C.A.*, **32**, 801 (1938); German pat., 677,665, *C.A.*, **33**, 9667 (1939); British pat., 467,549, *C.A.*, **31**, 8547 (1937).

188. I. G. Farbenind. A.-G., French pat., 829,926, *C.A.*, **33**, 1760 (1939); British pat., 507,378, *C.A.*, **34**, 636 (1940).

189a. I. G. Farbenind. A.-G., British pat., 490,043, *C.A.*, **33**, 644 (1939). *b.* Sergeev, *J. Gen. Chem.* (*U.S.S.R.*), **1**, 279 (1931); *C.A.*, 26, 2184 (1932).

190. Martin and Hirt, U. S. pat., 2,207,021, *C.A.*, **34**, 8114 (1940); British pat., 508,148, *C.A.*, **34**, 1102 (1940); Swiss pat., 200,667, *C.A.*, **33**, 8859 (1939).

191. Gabel and Grinberg, *J. Applied Chem.* (*U.S.S.R.*), **12**, 1481 (1939).

192. Hoffman-LaRoche Co. A.-G., Swiss pats., 206,925, *C.A.*, **34**, 7543 (1940); 208,882, *C.A.*, **35**, 3652 (1941).

193. Mendoza, U. S. pat., 1,766,949, *C.A.*, **24**, 4405 (1930); British pat., 297,855, *C.A.*, **23**, 2724 (1929).

194. I. G. Farbenind. A.-G., French pat., 46,097 (addition to 774,122), *C.A.*, **30**, 6009 (1936).

195. Witt and Uermenyi, *Ber.*, **46**, 296 (1913).

196. Witt and Truttwin, *Ber.*, **47**, 2786 (1914).

197. Warren and Smiles, *J. Chem. Soc.*, 2775 (1932).

198. Other information on this reaction is given in Chapter VI on sulfonamides and related compounds.

199. I. G. Farbenind. A.-G., British pat., 506,227, *C.A.*, **33**, 9328 (1939); Lab. francais de chimiothérapie and Girard, French pat., 844,220, *C.A.*, **34**, 7543 (1940).

200. Sugasawa and Sakurai, *J. Pharm. Soc. Japan*, 60, 22 (1940); *C.A.*, **34**, 3704 (1940).

201. Fromm and Wittmann, *Ber.*, **41**, 2264 (1908); La Croix, *Bull. soc. chim.*, **35**, 1436 (1924).

202. Schering A.-G., British pat., 510,127, *C.A.*, **34**, 4079 (1940); Kereszty and Wolf, Hungarian pat., 121,910, *C.A.*, **34**, 1336 (1940).

203a. Raiziss, Clemence, Severac, and Moetsch, *J. Am. Chem. Soc.*, **61**, 2763 (1939); Van Arendonk and Kleiderer, *ibid.*, 62, 3521 (1940). *b.* Bogert and Mandelbaum, *ibid.*, **45**, 3045 (1923). *c.* Ellingworth and Rose, British pat., 517,421, *C.A.*, **35**, 6973 (1941).

204a. Groves and Turner, *J. Chem. Soc.*, 509 (1929); LeFèvre and Turner, *ibid.*, 1113 (1927). *b.* Raiziss and Clemence, U. S. pat., 2,248,283, *C.A.*, **35**, 6602 (1941).

205. Bauer, *J. Am. Chem. Soc.*, **61**, 617 (1939).

206. Henry and Gray, British pat., 491,265, *C.A.*, **33**, 1104 (1939).

207a. Buttle, Dewing, Foster, Gray, Smith, and Stephenson, *Biochem. J.*, **32**, 1101 (1938). *b.* Pöhls and Mietzsch, U. S. pat., 2,218,030, *C.A.*, **35**, 1072 (1941).

208. Halpern and Dubost, *Bull. soc. chim. biol.*, **21**, 717 (1939).

209. Passedouet and Vaisman, *Compt. rend. soc. biol.*, **130**, 130 (1939).

210. Trapl, *Acta Dermato-Venereol.*, 20, 248 (1939); *C.A.*, **34**, 464 (1940).

211. Gray, *J. Chem. Soc.*, 1202 (1939).

212. Buttle and co-workers, *Lancet*, 1331 (1937); Fourneau, Tréfouël, Tréfouël, Nitti, and Bovet, *Bull. acad. med.*, **118**, 210 (1937), *Compt. rend.*, 204, 1763 (1937); Bauer and Rosenthal, *Pub. Health Rept.*, **53**, 40 (1938).

213. Raiziss, Severac, Moetsch, and Clemence, *Proc. Soc. Exptl. Biol. Med.*, **39**, 339 (1939).

214. Nitti, Bovet, and Hamon, *Compt. rend. soc. biol.*, **128**, 26 (1938).

215. Bovet, Tréfouël, Tréfouël, Nitti, and Hamon, *Ann. Inst. Pasteur*, **61**, 812 (1938).

216. Wyss-Chodat and Paillard, *C.A.*, **34**, 4225 (1940).

217. For examples see Greey, McLaren, and Lucas, *Can. Med. Assoc. J.*, **40**, 319 (1939); Kolmer, Raiziss, and Rule, *J. Lab. Clin. Med.*, **24**, 779 (1939); Raiziss, Kolmer, and Rule, *J. Infectious Diseases*, **66**, 138 (1940).

218. Rist, *Compt. rend. soc. biol.*, **130**, 972 (1939).

219. Fourneau, Tréfouël, Tréfouël, Nitti, and Bovet, *Compt. rend. soc. biol.*, **127**, 393 (1938).

220. Warren and Smiles, *J. Chem. Soc.*, 2774 (1932).

221. Levi and Smiles, *ibid.*, 1488 (1932).

222. Evans and Smiles, *ibid.*, 181 (1935).

223. Evans and Smiles, *ibid.*, 329 (1936).

224*a*. Mellander, *Svensk. Kem. Tid.*, **46**, 99 (1934); *C.A.*, **28**, 5408 (1934). *b*. Bäckland, *Arkiv Kemi, Mineral. Geol.*, **14A**, No. 1, 25 pp. (1940); *C.A.*, **34**, 7860 (1940). *c*. Ramberg and Mellander, *Arkiv Kemi, Mineral. Geol.*, **11B**, No. 31 (1934); *C.A.*, **28**, 4296 (1934). *d*. Urquhart and Connor, *J. Am. Chem. Soc.*, **63**, 1483 (1941).

225*a*. Michael and Comey, *Am. Chem. J.*, **5**, 116 (1883). *b*. Ashley and Shriner, *J. Am. Chem. Soc.*, **54**, 4410 (1932). *c*. Soc. pour l'ind. à Bâle, German pat., 646,630, *C.A.*, **31**, 6257 (1937); British pat., 415,877, *C.A.*, **29**, 858 (1935).

226. Kohler and MacDonald, *Am. Chem. J.*, **22**, 234 (1899).

227. Tröger and Lux, *Arch. Pharm.*, **247**, 618 (1910).

228. Tröger and Berndt, *J. prakt. Chem.*, [2] **102**, 1 (1921).

229. Tröger and Nolte, *J. prakt. Chem.*, [2] **103**, 163 (1921); Tröger and Dunkel, *ibid.*, **104**, 311 (1922).

230. Twist and Smiles, *J. Chem. Soc.*, **127**, 1248 (1925).

231. Otto, *Ber.*, **19**, 1835 (1886).

232*a*. Kohler and Reimer, *Am. Chem. J.*, **31**, 176 (1904). *b*. Ufer, German pat., 676,013, *C.A.*, **33**, 6612 (1939). *c*. Toennies and Kolb, *J. Biol. Chem.*, **140**, 131 (1941).

233. Lovén, *Ber.*, **17**, 2818 (1884).

234. Alden and Houston, *J. Am. Chem. Soc.*, **56**, 413 (1934).

235. Price and Brazier, *J. Chem. Soc.*, **107**, 1367 (1915).

236. Lovén and Ahlberg, *Ber.*, **54B**, 227 (1921); Ahlberg, *Ber.*, **55B**, 1279 (1922); *J. prakt. Chem.*, [2] **107**, 241 (1924); *Ber.*, **61B**, 811, 817, 827 (1928); *Svensk Kem. Tid.*, **44**, 48 (1932); *C.A.*, **26**, 4060 (1932); Backer and Meyer, *Rec. trav. chim.*, **46**, 212 (1927).

237. Lovén and Johansson, *Ber.*, **48**, 1254 (1915); Johansson, *Kem. Tidskrift*, **29**, 85 (1917); *C.A.*, **11**, 2660 (1918).

238*a*. Tröger and Hille, *J. prakt. Chem.*, [2] **71**, 201 (1905). *b*. Tröger and Volkmer, *ibid.*, [2] **71**, 236 (1905).

239. Tröger and Wunderlich, *Arch. Pharm.*, **253**, 214 (1915).

240. Tröger and Lindner, *J. prakt. Chem.*, [2] **78**, 1 (1908).

241. Tröger and Vasterling, *ibid.*, [2] **72**, 323 (1905).

242. Tröger and Beck, *ibid.*, [2] **87**, 289 (1913).

243*a*. Tröger and Prochnow, *ibid.*, [2] 78, 123 (1908). *b*. Tröger and Bremer, *Arch. Pharm.*, **247**, 613 (1910).

244. Soc. pour l'ind. chim. à Bâle, Swiss pat., 190,628, *C.A.*, **32**, 801 (1938).

245. Tröger and Köppen-Kastrop, *J. prakt. Chem.*, [2] **104**, 335 (1922).

246. Tröger and Krückeberg, *ibid.*, [2] **114**, 249 (1926).

247. Tröger and Ungar, *ibid.*, [2] **112**, 243 (1926).

248. Tröger and Lux, *Arch. Pharm.*, **247**, 618 (1910).
249. Tröger and Kroseberg, *J. prakt. Chem.*, [2] **87**, 67 (1913).
250. Tröger and Mueller, *Arch. Pharm.*, **252**, 32 (1914).
251. Tröger and Wunderlich, *J. prakt. Chem.*, [2] **101**, 157 (1920).
252. Otto, *ibid.*, [2] **30**, 345 (1884).
253*a*. D'Ouville and Connor, *J. Am. Chem. Soc.*, **60**, 34 (1938). *b*. Jensen and Lundquist, *Dansk. Tids. Farm.*, **14**, 129 (1940).
254. Pomerantz and Connor, *J. Am. Chem. Soc.*, **61**, 3386 (1939).
255. Pomerantz and Connor, *ibid.*, **61**, 3139 (1939).
256*a*. Ziegler and Connor, *ibid.*, **62**, 1049 (1940). *b*. Barr, Ziegler, and Connor, *ibid.*, **63**, 105 (1941).
257. Frerichs, *Arch. Pharm.*, **237**, 289 (1899).
258. Kohler and MacDonald, *Am. Chem. J.*, **22**, 219 (1899).
259*a*. Tröger and Beck, *J. prakt. Chem.*, [2] **87**, 289 (1913). *b*. Tröger and Brohm, *ibid.*, [2] **111**, 176 (1925).
260. R. and W. Otto, *ibid.*, [2] **36**, 401 (1887).
261*a*. Tröger and Bolm, *ibid.*, [2] **55**, 398 (1897). *b*. Tröger and Dimitroff, *ibid.*, [2] **111**, 193 (1925).
262. Delisle, *Ann.*, **260**, 262 (1890).
263. Tröger and Mueller, *Arch. Pharm.*, **252**, 32 (1914).
264. Gibson, *J. Chem. Soc.*, 2637 (1931); *ibid.*, 1819 (1932); 306 (1933); Kipping, *ibid.*, 18 (1935); Gibson, *J. Am. Chem. Soc.*, **55**, 2611 (1933).
265. Tröger and Menzel, *J. prakt. Chem.*, [2] **103**, 188 (1921); Tröger and Pape, *ibid.*, [2] **114**, 199 (1926); Tröger and Kestenbach, *ibid.*, [2] **114**, 221 (1926).
266. Arndt, Kirsch, and Nachtwey, *Ber.*, **59B**, 1079 (1926).
267. Feist, *Ber.*, **58B**, 2311 (1925).
268. Weston and Suter, *J. Am. Chem. Soc.*, **61**, 389 (1939).
269*a*. Surrey and Lindwall, *ibid.*, **62**, 173 (1940). *b*. Colonna, *Gazz. chim. ital.*, **70**, 154 (1940); Ochiai and Takubo, *J. Pharm. Soc. Japan*, **61**, 1 (1941). *c*. Winter and Reinhart, *J. Am. Chem. Soc.*, **62**, 3508 (1940).
270. Courtot and Zwilling, *Congr. chim. ind. compt. rend.*, 18th Congr., Nancy (September–October, 1938), pp. 796–801; *C.A.*, **33**, 6313 (1939).
271. King and Ware, *J. Chem. Soc.*, 873 (1939).
272. Oddo and Mingoia, *Gazz. chim. ital.*, **56**, 782 (1926); *C.A.*, **21**, 1458 (1927).
273. Claasz, *Ber.*, **49**, 1408, 1880 (1916).
274. Kretov, *J. Russ. Phys. Chem. Soc.*, **62**, 1 (1930); *C.A.*, **24**, 4257 (1930).
275. Alexander and McCombie, *J. Chem. Soc.*, 1913 (1931).
276. Lewin, *J. prakt. Chem.*, [2] **127**, 77 (1930).
277. Lewin and Tschulkoff, *ibid.*, [2] **128**, 171 (1930).
278. Müller and Metzger, *ibid.*, **114**, 123 (1926).
279. Ufer, U. S. pat., 2,163,180, *C.A.*, **33**, 8030 (1939); French pat., 789,947, *C.A.*, **30**, 2992 (1936).
280. Rothstein, *J. Chem. Soc.*, 684 (1934).
281. Kohler and Potter, *J. Am. Chem. Soc.*, **57**, 1316 (1935).
282. Kharasch, May, and Mayo, *J. Org. Chem.*, **3**, 175 (1938).
283. Tröger and Bolte, *J. prakt. Chem.*, [2] **103**, 163 (1921).
284. Ufer, U. S. pats., 2,103,879, and 2,103,880, *C.A.*, **32**, 1813 (1938); British pat., 450,559, *C.A.*, **31**, 114 (1937).

285. Reppe and Ufer, German pat., 636,077, *C.A.*, **31**, 704 (1937); British pat., 444,501, *C.A.*, 30, 5810 (1936); Ufer, German pat., 635,298, *C.A.*, **31**, 115 (1937).

286. Ufer, German pat., 663,992, *C.A.*, **33**, 174 (1939).

287. Ufer, U. S. pat., 2,140,608, *C.A.*, **33**, 2535 (1939); U. S. pat., 2,140,609, *C.A.*, **33**, 2541 (1939); German pat., 635,298, *C.A.*, **31**, 115 (1937); British pat., 442,525, *C.A.*, 30, 4691 (1936); French pat., 783,884, *C.A.*, **29**, 8356 (1935).

288. Alder, Rickert, and Windemuth, *Ber.*, **71B**, 2451 (1938).

289*a*. Otto, *Ann.*, **283**, 184 (1894). *b*. Tröger and Hinze, *J. prakt. Chem.*, [2] **55**, 202 (1897).

290*a*. de Bruin, *Verslag. Akad. Wetenschappen*, **23**, 445 (1914); *C.A.*, 9, 623 (1915). *b*. Eigenberger, *J. prakt. Chem.*, [2] **127**, 307 (1930). *c*. Eigenberger, *ibid.*, [2] **129**, 312 (1931). *d*. Eigenberger, *ibid.*, [2] **131**, 289 (1931). *e*. Backer and Bottema, *Rec. trav. chim.*, **51**, 294 (1932). *f*. Backer and Strating, *ibid.*, **53**, 525 (1934). *g*. Böeseken and van Zuydewijn, *Proc. Acad. Sci. Amsterdam*, **37**, 760 (1934); *C.A.*, **29**, 2145 (1935). *h*. van Zuydewijn and Böeseken, *Rec. trav. chim.*, **53**, 673 (1934). *i*. Backer and Strating, *ibid.*, **54**, 170 (1935). *j*. Sorokin and Puzitzkii, *Sintet. Kauchuk*, No. 6, 12–16 (1933); *C.A.*, **28**, 3339 (1934). *k*. Staudinger, French pat., 698,857, *C.A.*, **25**, 3360 (1931). *l*. Backer and Bolt, *Rec. trav. chim.*, **54**, 538 (1935). *m*. van Zuydewijn, *ibid.*, **56**, 1047 (1937). *n*. **57**, 445 (1938). *o*. Backer and Strating, *ibid.*, **56**, 1069 (1937); *p*. Backer, Strating, and Kool, *ibid.*, **58**, 778 (1939).

291*a*. Sauter, *Z. Krist.*, **83**, 340 (1932). *b*. Backer, Stevens, and van der Bij, *Rec. trav. chim.*, **59**, 1141 (1940).

292. van Zuydewijn, *ibid.*, **57**, 806 (1938).

293*a*. I. G. Farbenind. A.-G., British pat., 489,974, *C.A.*, **33**, 644 (1939). *b*. French pat., 847,254, *C.A.*, **35**, 5519 (1941).

294. Hinsberg, *Ber.*, **48**, 1611 (1915).

295. Autenrieth, *Ann.*, **259**, 336 (1890).

296. Reuterskiöld, *J. prakt. Chem.*, [2] **129**, 121 (1931).

297. Kohler and Larsen, *J. Am. Chem. Soc.*, **57**, 1448 (1935).

298. Kohler and MacDonald, *Am. Chem. J.*, **22**, 219 (1899).

299. See also Hinsberg, *Ber.*, **49**, 2593 (1916).

300. Meyer, *Chem. Zentr.*, I, 455 (1901).

301. Hilditch, *J. Chem. Soc.*, **93**, 1524 (1908).

302. Smiles and Hilditch, *ibid.*, **91**, 519 (1907).

303. Posner, *Ber.*, **36**, 299 (1903).

304. Holmberg, *Ber.*, **40**, 1742 (1907); Baumann, *Ber.*, **19**, 2811 (1886).

305. Laves, *Ber.*, **25**, 356 (1892).

306. Posner, *Ber.*, **35**, 501 (1902).

307*a*. Gibson, *J. Chem. Soc.*, 2637 (1931). *b*. Kipping, *ibid.*, 1506 (1933).

308. Posner and Fahrenhorst, *Ber.*, **32**, 2768 (1899).

309. Steinkopf and Hübner, *J. prakt. Chem.*, [2] **141**, 193 (1934); Gibson, *ibid.*, [2] **142**, 218 (1935).

310. Fromm, *Ann.*, **253**, 141 (1889).

311*a*. Stutz and Shriner, *J. Am. Chem. Soc.*, **55**, 1242 (1933). *b*. Shriner, Struck, and Jorison, *ibid.*, **52**, 2068 (1930).

312. Fromm, Forster, and v. Scherschewitzki, *Ann.*, **394**, 344 (1912).

313. Bayer and Co., German pat., 49,073, *Frdl.*, **2**, 521.

314. Kötz, *Ber.*, **33**, 1126 (1900).

315. Kipping, *J. Chem. Soc.*, 18 (1935).

316. Autenrieth, *Ann.*, **259**, 367 (1890).

317*a*. Baumann, *Ber.*, **19**, 2811 (1886). *b*. Stuffer, *Ber.*, **23**, 3226 (1890).

318. Baumann and Escales, *Ber.*, **19**, 2815 (1886).

319. Ramberg and Samén, *Arkiv Kemi, Mineral. Geol.*, **11B**, No. 40 (1934); **12A**, No. 8 (1936); *C.A.*, **28**, 6103 (1934); **30**, 4077 (1936).

320. Bischoff, *Ber.*, **30**, 487 (1897).

321. Recsei, *Ber.*, **60B**, 1420 (1927).

322. Kast, *Chem. Zentr.*, 718 (1888); *Pharm. Zentralhalle*, **29**, 224, 438 (1888); Baumann and Kast, *Z. Physiol. Chem.*, **14**, 52 (1890); Hildebrandt, *Arch. exp. Path. Pharmakol.*, **63**, 92 (1907).

323. Vitali, *Boll. chim.-farm.*, **39**, 461, 497 (1900); *Chem. Zentr.*, II, 646 (1900).

324. Fuchs, *Chem. Ind.*, 26, 80 (1903).

325. Recsei, *Ber.*, **60B**, 1836 (1927).

326. Michael and Palmer, *Am. Chem. J.*, **6**, 254 (1884).

327. Otto, *J. prakt. Chem.*, [2] **51**, 286 (1895).

328. R. Otto and W. Otto, *Ber.*, **21**, 1693 (1888).

329. Otto, *Ber.*, **27**, 3055 (1894).

330. Otto, *Ber.*, **19**, 1835 (1886); *J. prakt. Chem.*, [2] **40**, 530 (1889).

331. Otto, *ibid.*, [2] **36**, 437 (1887).

332. Beckmann, *ibid.*, [2] **17**, 469 (1878).

333. Stuffer, *Ber.*, **23**, 3232 (1890).

334. Ewerlof, *Ber.*, **4**, 717 (1870).

335*a*. Reuterskiöld, *J. prakt. Chem.*, [2] **129**, 121 (1931). *b*. Also see the monograph abstracted in *C.A.*, **34**, 2791 (1940).

336*a*. Fasbender, *Ber.*, **21**, 1473 (1888). *b*. Baumann and Walter, *Ber.*, **26**, 1124 (1893). *c*. Fromm and Ungar, *Ber.*, **56B**, 2286 (1923).

337. Fromm and Raiziss, *Ann.*, **374**, 101 (1910).

338. Stuffer, *Ber.*, **23**, 1412 (1890).

339. Otto and Damkohler, *J. prakt. Chem.*, [2] **30**, 171, 321 (1884).

340. Reuterskiöld, *ibid.*, [2] **127**, 269 (1930).

341*a*. Crafts, *Ann.*, **125**, 123 (1863). *b*. Purgotti, *C.A.*, **13**, 2515 (1919).

342*a*. Hurtley and Smiles, *J. Chem. Soc.*, 1821 (1926). *b*. Heppenstall and Smiles, *ibid.*, 899 (1938).

343. Tröger and Meine, *J. prakt. Chem.*, [2] **68**, 320 (1903); Otto, *ibid.*, [2] **36**, 449 (1887).

344. Müller, Scherer, and Schumacher, U. S. pat., 2,108,606, *C.A.*, **32**, 2958 (1938).

345. MacLean and Adams, *J. Am. Chem. Soc.*, **55**, 4681 (1933).

346*a*. Fischer, Mahler, and Modersohn, German pat., 622,494, *C.A.*, **30**, 1392 (1936). *b*. Livingston and Loudon, *J. Chem. Soc.*, 246 (1937).

347. Soc. pour l'ind. chim. à Bâle, French pat., 822,226, *C.A.*, **32**, 4176 (1938); British pat., 478,624 and Swiss pats., 199,651–199,653, *C.A.*, **33**, 3531 (1939); Swiss pats, 200,917–200,920; Felix, Capeller, and Sallmann, *C.A.*, **35**, 1412 (1941).

348. Loudon, *J. Chem. Soc.*, 902 (1939).

349. Chardonnens and Venetz, *Helv. Chim. Acta*, **22**, 822 (1939).

350. Otto, *Ber.*, **24**, 1833 (1891).

351. Foster and Reid, *J. Am. Chem. Soc.,* **46,** 1944 (1924).
352. Fromm and Seibert, *Ber.,* **55B,** 1014 (1922).
353. Ufer, German pat., 635,396, *C.A.,* **31,** 112 (1937).
354. Rothstein, *J. Chem. Soc.,* 309, 317 (1937).
355. Gilman and Peterson, *J. Am. Chem. Soc.,* **48,** 423 (1926).
356. Otto and Tröger, *Ber.,* **25,** 3423 (1892).
357. Otto, *Ber.,* 22, 1967 (1889).
358. R. and W. Otto, *J. prakt. Chem.,* [2] **36,** 417 (1887).
359. Hann, *J. Am. Chem. Soc.,* **57,** 2167 (1935).
360. R. and W. Otto, *J. prakt. Chem.,* [2] **36,** 401 (1887).
361. Tröger and Bolm, *ibid.,* [2] **55,** 399 (1897).
362. Tröger and v. Seelin, *ibid.,* [2] **105,** 208 (1923); Tröger and Pahle, *ibid.,* [2] **112,** 221 (1926).
363. Tröger and Köppen-Kastrop, *ibid.,* [2] **104,** 335 (1922).
364. Posner, *Ber.,* **35,** 816 (1902).
365*a*. Fromm, *Ann.,* **253,** 166 (1889). *b.* Laves, *Ber.,* **25,** 361 (1892).
366*a*. Helfrich and Reid, *J. Am. Chem. Soc.,* **42,** 1208 (1920). *b.* Fromm and Ungar, *Ber.,* **56B,** 2286 (1923). *c.* Laves, *Ber.,* **23,** 1416 (1890). *d.* **25,** 347 (1892).
367. Stuffer, *Ber.,* **23,** 1414 (1890).
368. Ray, *J. Chem. Soc.,* **123,** 2174 (1923).
369*a*. Baumann, *Ber.,* **23,** 1872 (1890). *b.* Otto, *Ber.,* **27,** 3057 (1894). *c.* Autenrieth, *Ber.,* **24,** 169, 1516 (1891). *d.* Otto and Rossing, *Ber.,* **24,** 234 (1891). *e.* Tröger and Hornung, *J. prakt. Chem.,* [2] **56,** 454 (1897). *f.* Otto, *Ann.,* **283,** 204 (1894).
370. Stuffer, *Ber.,* **23,** 3226 (1890).
371. Fromm and Jörg, *Ber.,* **58B,** 304 (1925).
372. Kotz, *Ber.,* **33,** 1123 (1900).
373. Posner, *Ber.,* **38,** 656 (1905).
374. Backer and Dykstra, *Rec. trav. chim.,* **51,** 1173 (1932).
375. Hinsberg, *J. prakt. Chem.,* [2] **142,** 135 (1935).
376. Backer, *Rec. trav. chim.,* **55,** 17 (1936).
377. Solonina, *J. Russ. Phys.-Chem. Soc.,* 30, 826 (1898); *Chem. Zentr.,* I, 248 (1899).
378. Mathews and Elder, British pat., 11,635, *C.A.,* 9, 2971 (1915).
379. Seyer and King, *J. Am. Chem. Soc.,* 55, 3140 (1933).
380. Staudinger and Ritzenthaler, *Ber.,* **68B,** 455 (1935).
381*a*. Frederick, Cogan, and Marvel, *J. Am. Chem. Soc.,* **56,** 1815 (1934). *b.* Hunt and Marvel, *ibid.,* **57,** 1691 (1935). *c.* Ryden, Glavis, and Marvel, *ibid.,* **59,** 1014 (1937). *d.* Marvel and Glavis, *ibid.,* **60,** 2622 (1938). *e.* Kharasch and Sternfeld, *ibid.,* **62,** 2559 (1940).
382*a*. Marvel and Sharkey, *ibid.,* **61,** 1603 (1939). *b.* Snow and Fry, *Ind. Eng. Chem.,* **30,** 176 (1938). *c.* Pipik, *C.A.,* **33,** 7280 (1939).
383*a*. Ryden and Marvel, *J. Am. Chem. Soc.,* **57,** 2311 (1935). *b.* Marvel and Glavis, *ibid.,* **60,** 2622 (1938). *c.* Marvel and Dunlap, *ibid.,* **61,** 2709 (1939).
384. Ryden and Marvel, *ibid.,* **58,** 2047 (1936).
385. Marvel, Davis, and Glavis, *ibid.,* **60,** 1450 (1938).
386. Marvel and Williams. *ibid.,* **61,** 2710, 2714 (1939).

387. **Fitch**, U. S. pat., 2,045,592, *C.A.*, **30**, 5683 (1936); **Frey**, **Fitch**, and **Snow**, U. S. pat., 2,114,292, *C.A.*, **32**, 4698 (1938); **Marvel**, U S pat, 2,138,584, *C.A.*, **33**, 2246 (1939); **Frederick** and **Marvel**, U. S. pat., 2,201,544, *C.A.*, **34**, 6386 (1940); **Brubaker** and **Harmon**, U. S. pat., 2,241,900, *C.A.*, **35**, 5217 (1941).

388. **Carothers**, U. S. pat., 2,201,884, *C.A.*, **34**, 6389 (1940).

INDEX

In this index compounds are named by the *Chemical Abstracts* method in which substituents appear in alphabetical order as in *bromochloronitrobenzenesulfonamide.* Compounds are listed by names and not by classes. Thus *ethyl methyl sulfone* is to be found under *ethyl* rather than under *sulfone.*

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